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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

THE QUALITY OF SURFACE WATERS IN MINNESOTA

BY

R. B. DOLE AND F. F. WESBROOK

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MAP OF MINNESOTA SHOWING LOCATION OF SAMPLING STATIONS.

THE QUALITY OF SURFACE WATERS IN MINNESOTA.

By R. B. Dole and F. F. Wesbrook.

INTRODUCTION.

The following paper outlines the general characteristics of surface waters in Minnesota and the various factors that tend to modify the quality of the drainage. It includes the results of nearly two years' field and laboratory work done by the United States Geological Survey in cooperation with the Minnesota State board of health. First the general features, both natural and economic, that influence the quality of the meteoric water and impart to the lakes and streams their essential characteristics are reviewed. Next each drainage area is considered in detail, the streams are described, the sources of pollution are discussed, and the results of chemical analyses and bacteriological examinations are given. Statistics are presented regarding practically all of the municipal water supplies in the State, and the relative value of the surface and ground waters for general consumption is discussed. At the end is a description of the laboratory methods employed in the chemical and bacteriological work.

During the summer of 1903 arrangements were made whereby a study of Minnesota surface waters was commenced jointly by the United States Geological Survey, the Minnesota State board of health, and the chemical department of the University of Minnesota. Certain sections of the State were assigned to each party of the agreement for investigation. In pursuance of this project samples were collected at Brainerd, Hastings, Mankato, Prescott, Rochester, St. Cloud, Sauk Rapids, and Wabasha, during the fall of 1903, by representatives of the Minnesota State board of health. Three trips over the territory assigned to the United States Geological Survey were made by R. B. Dole, assistant hydrographer, between November 25, 1903, and May 22, 1904, during which time samples were collected at Aitkin, Bemidji, Biwabik, Brainerd, Cass Lake, Cloquet, Crookston, Ely, Eveleth, Grand Rapids, Hibbing, Sparta, Tower, and Virginia. During the first seven months of 1904 samples were collected by representatives of the State board of health at Anoka, Fort Snelling, Granite Falls, Hastings, Mankato, Montevideo, New Ulm, Ortonville, Prescott, Redwood Falls, Rochester, and Wabasha. (Pl. I.) At each place

visited samples were collected in glass bottles and forwarded by express for chemical analysis to the State laboratories, where they were examined by H. C. Carel, assistant professor in medical chemistry, University of Minnesota, who was employed by the State board of health to perform the chemical examinations of water. Samples for bacteriological examination were also collected at the same time and plated in the field and the cultures were sent by express to the laboratory for incubation and examination. In addition, field tests were made for certain constituents at the time of collection.

In the summer of 1904 an agreement between the United States Geological Survey and the State board of health was made, by which an employee of the Survey was detailed by the Survey and appointed by the board to do such chemical work from August 1, 1904, to July 31, 1905, inclusive, as might be necessary in an extended examination of waters of the lakes and streams of Minnesota. During that period the chemical analyses were performed by R. B. Dole, assistant hydrographer, in a laboratory at Minneapolis specially equipped for the purpose by the State board of health. The bacteriological examination of the water samples was conducted as formerly in the laboratory of the State board of health, by Dr. E. H. Beckman, assistant bacteriologist to the board. Both the chemical and the bacteriological work were, during the entire cooperation, under the immediate supervision of Dr. F. F. Wesbrook, director of the laboratories of the State board of health of Minnesota. In order to continue the comprehensive survey of the surface waters in the State, points were selected in each drainage area at which samples should be taken at regular intervals for examination. Sixty-five stations were thus established, at which samples were taken in regular series—one sample during the fall of 1904, one during the winter of 1904–5, and one during the spring of 1905.

In addition to the results obtained by the laboratory work thus performed, it was considered especially important to procure all available information concerning matters of hydro-economic importance in the sections visited, and a large amount of time was expended in gathering data concerning every feature of municipal activity which in any way affects water in its relation to public health or public utilities. At every place where it was possible, a personal inspection was made of waterworks systems, sewerage, and effluent-discharging factories, and detailed information was obtained concerning water and sewerage systems, ice supply, sewage-disposal works, water-borne diseases, and general water resources. In this manner information was procured regarding a majority of the principal cities and villages. In the spring of 1905 correspondence was carried on with reliable persons in such important settlements as had not been visited in order to procure the same kind of information, so that by the end of July, 1905, data were

on file concerning practically every settlement in the State having a population of more than 1,000 according to the census of 1900, and also concerning practically every waterworks system in the State. Active field work was discontinued on June 30, 1905.

For many courtesies extended and for information given, acknowledgments are here made to the health officers, waterworks superintendents, city clerks, and others who collaborated with the authors in this investigation. Special thanks are due to Dr. H. M. Bracken, secretary of the State board of health, for his enthusiastic support and for his vast local and general knowledge of the State, which was at all times made available by him in the work; thanks are also due to the individual members of the State board of health, who supported the work heartily throughout and by their interest made it possible, and to the individual members of the staff of the laboratories of the State board of health, who rendered every assistance whenever it was desired. Mr. Marshall O. Leighton, chief hydrographer, water resources branch U. S. Geological Survey, originally suggested the work and has followed it carefully throughout, guiding it and helping in the correlation of the practical and scientific sides at all times.

NATURAL FEATURES.

TOPOGRAPHY.

The greater part of Minnesota is slightly rolling prairie, forest, or swamp land lying between 1,000 and 1,500 feet above sea level. Its watersheds are usually morainic in character, elevated but little above the surrounding country. The northeastern section, above Lake Superior, is the only part that can be called mountainous. There a series of ridges comprising the Sawteeth and Mesabi ranges, extends from the international boundary, near Gunflint Lake, southwestward to Mississippi River at Grand Rapids, through Cook, Lake, St. Louis, and Itasca counties. It includes the Vermilion and Mesabi iron-bearing districts. The highest recorded elevation is 2,230 feet[a] above the sea in the Misquah Hills, Cook County. The next highest section of elevated topography, known as the Leaf Hills, extends in a nearly north-south line through Ottertail and Douglas counties. These hills stretch northward through Becker and Clearwater counties in a plateau; on the east and the west they slope gently to the broad valleys of Mississippi River and Red River, respectively. The highest part of this tract is not over 1,750 feet above sea level. In the southwestern part of the State the Coteau des Prairies, commonly known as the Dakota foothills, enter from South Dakota and extend southeastward through Lyon, Murray, and Nobles counties to the Iowa boundary. They are composed of drift deposits and in Minnesota

[a] Winchell, N. H., Geol. and Natural History Survey of Minnesota, Final Rept., vol. 4, p. 317.

reach a maximum elevation of about 2,000 feet above the sea. Low and comparatively insignificant ridges, generally glacial in origin, form the watersheds throughout the rest of the State. The lowest parts of the State are the points at which the three great drainage systems cross its boundary. St. Louis River enters Lake Superior at an elevation of 602 feet[a] above sea level; Red River leaves the State at a mean elevation of 767 feet;[b] and Mississippi River is 617 feet[c] above the sea at the southern border.

HYDROGRAPHY.

RIVERS.

Minnesota contains within its boundaries the headwaters of three great drainage systems. Approximately one-tenth of its surface, comprising the St. Louis drainage area and the small streams entering Lake Superior, is in the Laurentian basin. The Hudson Bay system, through its great tributaries, Red River and Rainy River, drains about three-tenths of the State's area in the north and west sections. The rest of Minnesota is tributary to Mississippi River either directly or through its large branches, Missouri, Des Moines, Cedar, St. Croix, and Minnesota rivers.

In this report the water conditions are discussed under the following headings: (1) Mississippi River basin above Minnesota River; (2) Minnesota River basin; (3) St. Croix River basin; (4) Mississippi River basin between Minnesota River and the Iowa line; (5) Red River basin; (6) St. Louis River basin; (7) Rainy River basin; (8) Missouri River basin; (9) Des Moines River basin; (10) Cedar River basin.

Mississippi River drainage area above Minnesota River includes the river from its source to Fort Snelling and comprises the broad, gently sloping, forested and deforested lands in the north-central part of the State. (See Pl. II.)

Minnesota River drainage area comprises a broad tract extending across the State from South Dakota to the confluence of this river with Mississippi River at Fort Snelling. It includes parts of northeastern South Dakota and northern Iowa. (See Pl. III.)

St. Croix River drainage area includes part of eastern Minnesota and a large part of northwestern Wisconsin. The area tributary to Mississippi River above the southern boundary of Minnesota comprises more than three-quarters of Wisconsin, together with the country considered under St. Croix River, Minnesota River, and Mississippi River above Minnesota River. Therefore a discussion of this lower section and the main stream must necessarily have frequent reference to the rivers above mentioned. (See Pl. IV.)

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[a] Gannett, Henry, Dictionary of altitudes in the United States: Bull. U. S. Geol. Survey No. 274.
[b] Final Rept. Minnesota Geol. and Nat. Hist. Survey, vol. 1, p. 122.
[c] Mississippi River Commission. Charts of Mississippi River.

The Lake Superior basin in Minnesota is a comparatively small area, 20 to 100 miles wide, along the north and west shores of Lake Superior. Most of the streams are short and flow through an unsettled section of the State. The St. Louis drainage area comprises the greater part of this basin. (See Pl. VI.)

Red River drainage area in Minnesota extends from the middle of the western boundary north to Canada and east beyond Red Lake. North Dakota as far west as Devils Lake is tributary to Red River. A small tract in the northwestern corner of South Dakota lies in the basin of Red River. (See Pl. VII.)

Rainy River has tributary to it a strip of the northern part of Minnesota along the international boundary, extending from North Lake, a few miles northwest of Lake Superior, to Lake of the Woods.

Missouri River receives the drainage from a small area in the southwest corner of the State that is traversed by Rock and Little Sioux rivers.

Des Moines River has its headwaters in the southwestern part of Minnesota. Its drainage area includes parts of Pipestone, Murray, Nobles, Cottonwood, Jackson, and Martin counties.

Cedar River flows south through Freeborn, Mower, and Dodge counties near the southern boundary of the State.

LAKES.

Minnesota contains probably a larger number of lakes than any other State in the Union. The latest authority gives 84,682 square miles as the total area of the State, of which 3,824 square miles, or about 4.4 per cent, is water.[a] In addition to the above area 2,514 square miles of Lake Superior are within the State. Lake of the Woods forms part of the northern boundary. Lake Traverse and Bigstone Lake form part of the western boundary. Lake Pepin, an enlargement of Mississippi River, about 23 miles long and 3 miles wide, forms part of the eastern boundary. The following table shows the names, location, and areas of the principal lakes in the State:

TABLE 1.—*Principal lakes of Minnesota.*

Lake.	County.	Drainage area.	Water surface.
			Sq. miles.
Albert Lea	Freeborn	Cedar	
Alexander	Morrison	Mississippi	
Bass	Itasca	Mississippi	
Basswood	Lake	Rainy	
Bemidji	Beltrami	Mississippi	[b] 9.5
Benton	Lincoln	Minnesota	
Bigstone	Bigstone	Minnesota	[c] 18.5

[a] Gannett, Henry, The areas of the United States, the States, and the Territories: Bull. U. S. Geol. Survey No. 302, 1906, p. 5.
[b] Measured with planimeter from best available maps.
[c] Ann. Rept. Chief of Engrs. U. S. A. for 1898, p. 1838.

TABLE 1.—*Principal lakes of Minnesota*—Continued.

Lake.	County.	Drainage area.	Water surface.
			Sq. miles.
Bow String	Itasca	Rainy	[a] 18
Brule	Cook	Lake Superior	
Burntside	St. Louis	Rainy	[a] 14
Cass	Cass	Mississippi	[a] 29
Cormorant	Becker	Red	
Crooked	St. Louis	Rainy	
Dead	Ottertail	Red	
Fish	Crow Wing	Mississippi	
Green	Kandiyohi	Mississippi	
Greenwood	Cook	Lake Superior	
Gull	Cass	Mississippi	[a] 15
Gun Flint	Cook	Rainy	
Heron	Jackson	Des Moines	
Ida	Douglas	Mississippi	
Itasca	Clearwater	Mississippi	[a] 1.5
Kabetogama	St. Louis	Rainy	[a] 40
La Croix	St. Louis	Rainy	
Leech	Cass	Mississippi	[b] 233.80 [c] 173.19
Lida	Ottertail	Red	
Long	St. Louis	Rainy	
Loone	St. Louis	Rainy	
Millelacs	Millelacs	Mississippi	[d] 200
Miltona	Douglas	Mississippi	
Minnetonka	Hennepin	Mississippi	[a] 21
Minnewaska	Pope	Minnesota	[a] 11
Namekan	St. Louis	Rainy	
Nequowuon	St. Louis	Rainy	
Net	Itasca	Rainy	[a] 16
Osakis	Todd	Mississippi	
Ottertail	Ottertail	Red	[a] 23
Pelican	Crow Wing	Mississippi	[a] 16
Pelican	St. Louis	Rainy	[a] 21
Pepin	Goodhue	Mississippi	
Pine	Ottertail	Red	
Pokegama	Cass	Mississippi	[c] 12.20
Rainy	Itasca	Rainy	
Red (upper)	Beltrami	Red	[a] 207
Red (lower)	Beltrami	Red	[a] 287
St. Croix	Washington	St. Croix	
Saganaga	Cook	Rainy	
Sandy	Aitkin	Mississippi	[b] 16.52 [c] 8.00
Snowbank	Lake	Rainy	
Swan	Nicollet	Minnesota	[a] 16
Thief	Marshall	Red	
Traverse	Traverse	Red	[e] 13.8
Trout	St. Louis	Rainy	[a] 14
Vermilion	St. Louis	Rainy	[a] 66
West Battle	Ottertail	Red	
White Bear	Ramsey	Mississippi	
White Fish	Crow Wing	Mississippi	[a] 13
Winnibigoshish	Itasca	Mississippi	[b] 161.26 [c] 117.00

[a] Measured with planimeter from best available maps.
[b] High water; see p. 38.
[c] Low water; see p. 38.
[d] Geol. and Nat. Hist. Survey Minnesota, Final Rept., vol. 11, p. 613.
[e] Ann. Rept. Chief of Engrs. U. S. A. for 1898, p. 1838.

Most of the lakes are shallow and of glacial origin and are being gradually eliminated by silting, drainage, and perhaps other modifying agencies, so that it is only a question of time when their number will be greatly reduced.

DRAINAGE DITCHES.

On account of their unaccented topography large sections of the State contain extensive swamp areas which are agriculturally useless until they have been artificially drained. Some rivers are dispersed in large swamps covered with decaying black spruce, tamaracks, mosses, reeds, and small shrubs. In order to convert these areas into cultivable lands, canals and networks of drainage ditches have been dug. In 1893[a] the State legislature appropriated $100,000 for drainage work in Red River Valley and at the same time created a body known as the Red River Valley Drainage Commission, which, under the act of 1901, was reorganized as the drainage commission of the State of Minnesota. At the end of 1899 the commission had completed 117.47 miles of ditches in Clay, Grant, Kittson, Marshall, Norman, Polk, Traverse, and Wilkin counties. Since 1901 considerable work has been done in Wadena and Aitkin counties and in other sections. The total number of miles of ditches built by the State at the end of 1904 was 206.25. The work is by no means completed. Large swamp sections still remain in the unsettled portions of the Rainy Lake area and the upper Mississippi Valley. In addition to the work done by the State most of the counties in Minnesota have expended more or less money in draining lands within their borders and large areas have been drained by private corporations.

FLOODS.

The melting of snow in the spring and the accompanying heavy rainfall cause general floods throughout the State. In the fall heavy rains frequently cause the streams to run very high. During these floods the water, which is then in its worst condition from a sanitary standpoint, is most difficult to purify. A large quantity of organic matter that has accumulated on the surface of the ground is washed into the streams, together with disintegrated soil. With the rise of water and the consequent acceleration of stream velocity the sediment in the beds of the rivers is removed and carried on by the freshet. The enormous influx of soft water causes a diminution in the relative mineral content of the water, for while the turbidity of the streams is increased the percentage of dissolved matter is decreased. Fortunately, the absence of steep slopes in the greater part of the State prevents such disastrous floods as occur in mountainous regions; but

[a] Ralph, George A., Engineer's Rept. on State Drainage Work in Minnesota. Crookston, Minn., 1904.

the streams, nevertheless, sometimes show a marked general rise. The following table, compiled from records of stream measurements, shows the fluctuations of the principal rivers:

TABLE 2.—*Annual fluctuation of river level in Minnesota, in feet.*

River.	Place.	1901.	1902.	1903.	1904.	1905.	Maximum variation.
Mississippi	Aitkin[a]		11.8	11.4			14.0
Do	Sauk Rapids[b]			6.2	6.3	9.0	
Do	St. Paul[c]	6.2	6.4	10.5	7.3		20.6
Do	Hastings[a]		7.3	12.3	9.6		18.7
Do	Red Wing[c]	6.3	5.	8.9	6.4		15.3
Do	Reeds Landing[c]	8.	5.9	11.	7.6		15.8
Do	Winona[a]		5.5	12.3	7.6		18.2
Minnesota	Mankato[b]			16.8	6.5	10.7	
Red Lake	Crookston[b]		5.7	4.1	16.7	10.0	
Red	Grand Forks[b]			25.0	34.6	19.6	
Do	Moorhead[c]		3.7	6.9	14.3	11.2	33.4

[a] Mississippi River Commission. Stages of Mississippi River, 1901-1904.
[b] Report of progress of stream measurements, 1901-1905. Water Sup. and Irr. Papers, U. S. Geol. Survey.
[c] Daily river stages of the principal rivers of the United States, Weather Bureau, U. S. Dept. Agriculture, Pt. VII, W. B. No. 339.

Red River shows the greatest variation between high and low water. There are several reasons for this: (1) The land in the basin of this stream, though it is not mountainous, slopes gently to the principal water courses, and in level areas or places where there is opportunity for the water to collect in swamps ditches have been dug to assist in its rapid removal; (2) there are no forest trees in the greater part of the area to prevent rapid run-off and quick melting of snows and ice during a rise of temperature; (3) the area contains no large storage reservoirs except Red Lake. As a result of these factors the entire region has a quick run-off. The spring flood on Red River, as shown by gagings made by the United States Geological Survey at Grand Forks, N. Dak., occurs during the month of April and is the most important rise of the year. During the other spring months and in October heavy rainfall sometimes causes floods of less magnitude. The same condition exists on Minnesota River, the drainage area of which is in many respects similar to that of Red River.

Mississippi River in its upper part, as shown by gagings at Aitkin and at Sauk Rapids, is subject to a series of floods, which generally begin in April and last until the latter part of June. Summer rains cause freshets, but these are of much less importance than those on Red River. Heavy rains in September and October sometimes cause nearly as great freshets as those that occur in the spring. The conditions in the Mississippi drainage area are distinctly different from those in the Red River region, namely: (1) Much of the upper section of the valley is forested; (2) the area comprises large swamps; (3) extensive impounding reservoirs have been constructed for the purpose of holding back flood waters. Therefore floods on the Mississippi are not particularly high. Gagings of the lower river between St. Paul and the southern boundary of the State present a very com-

plex series of floods. At Winona, Minn., there is a rise in the latter part of March, another in April, and a still larger one during May. Doubtless these separate freshets are due to the fact that the ice and snow on different tributaries melt at different times. Heavy rainfalls usually cause freshets in September, October, or November.

CLIMATE.

Six climatological stations of the United States Weather Bureau are situated within or near the area under consideration: Duluth, Minn., at the head of Lake Superior, is in Lake Superior basin; Moorhead, Minn., about midway between the north and south boundaries of the State on its western border, is in Red River drainage area; Minneapolis and St. Paul, Minn., are situated in the eastern part of the State, near the confluence of Minnesota, upper Mississippi, and St. Croix rivers. Though Bismarck, N. Dak., is somewhat west of the region under study its climate may be considered typical of the western half of Red River drainage area. As a balance to this western station, La Crosse, Wis., near the southeastern corner of Minnesota, has been added.

TEMPERATURE.

The following table shows the mean temperature for each month throughout the year, calculated from the records of these stations, which have been established for periods ranging from fifteen to thirty-five years:

TABLE 3.—*Mean temperature in the Northwest, in degrees Fahrenheit.*[a]

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Duluth	10	13	24	38	48	58	66	65	57	45	29	17	39
Moorhead	3	5	22	42	55	64	68	66	56	44	25	12	38
Bismarck	6	9	22	42	55	64	69	68	57	44	27	15	40
St. Paul	12	15	28	46	58	67	72	71	60	48	31	19	44
Minneapolis	14	14	29	47	58	68	72	70	62	50	32	20	45
La Crosse	16	19	31	48	60	69	73	71	62	50	34	23	46
Mean	10	12	26	44	56	65	70	68	59	47	30	18	42

[a] From compiled records of the U. S. Weather Bureau, Washington, D. C.

The mean annual temperature for the entire region is 42° F. Though the variation from this figure from year to year is not large, the temperature reaches great extremes at certain seasons, so that the annual range considerably exceeds 100°, as is shown by Table 4.

TABLE 4.—*Extremes of temperature.*[a]

Station.	Highest observed.	Average maximum.	Lowest observed.	Average minimum.	Average annual range.
	°F.	°F.	°F.	°F.	°F.
Duluth	99	90	−41	−27	117
Moorhead	101	95	−48	−30	125
Bismarck	106	100	−44	−32	132
St. Paul	104	95	−40	−24	119
Minneapolis	102	95	−33	−24	119
La Crosse	102	95	−43	−22	117

[a] From compiled records of the U. S. Weather Bureau, Washington, D. C.

The average maximum temperature is about 95° and the average minimum temperature about −27°. January, the coldest month in the year, has a mean of 10°, and July, the warmest, a mean of 70°. The coldest section is Red River valley, and here also are found the greatest extremes of temperature. The region around Lake Superior, doubtless on account of its proximity to that large body of water, experiences the least changes. The portion having the highest average temperature is the southern half of Minnesota, in which the mean temperature is 45°.

PERIOD OF FROST.

In the northern section the temperature falls below freezing about the latter part of October and rises above that point early in April. The first severe frosts in autumn occur about the beginning of October and the last in spring about the first of May. The period during which the lakes and rivers are closed by ice is influenced not only by temperature, but by the velocity of flow and the size of the body of water and the percentage of ground water flowing into it. The following table gives approximately the period during which the principal rivers are closed at certain points:

TABLE 5.—*Ice period of principal rivers.*

River.	At—	Date closed.	Date opened.	Time closed (months).
Red	Moorhead	Dec. 1	Mar. 20	3.5
Minnesota	Mankato	Dec. 1	Apr. 1	4
Mississippi	Aitkin	Nov. 20	Apr. 10	5
Mississippi	St. Paul	Dec. 5	Mar. 20	3.5
Mississippi	Red Wing	Dec. 5	Mar. 20	3.5

In general, lakes are frozen over during the 5 months of November, December, January, February, and March. The port of Duluth is closed about 4 months in the year on account of ice in the Great Lakes. Devils Lake, a large body of water in North Dakota, in Red River drainage area,[a] is generally frozen from the middle of November to the first of May, a period of 5½ months. The thickness of the ice in different lakes and rivers varies from 1 to 45 inches.

PRECIPITATION.

The mean annual precipitation is 27 inches of rain and melted snow, though this figure may vary considerably from year to year in different parts of the area. It has been known to be as low as 11.03 inches at Bismarck, N. Dak., and as high as 44.74 inches at La Crosse, Wis.

[a] Newell, F. H., Water Supply and Irr. Paper No. 85, U. S. Geol. Survey, p. 239.

These extremes show the extent of variation between wet and dry years. The average rainfall at 6 stations in the Northwest is shown in Table 6.

TABLE 6.—*Precipitation in the Northwest.*[a]

Station.	Jan.	Feb.	Mar.	April.	May.	June.
Duluth	0.98	1.02	1.55	2.12	3.31	4.23
Moorhead	.66	.67	1.04	2.36	3.02	4.14
Bismarck	.56	.53	1.08	1.92	2.34	3.56
St. Paul	.89	.87	1.59	2.34	3.31	4.41
Minneapolis	.65	.78	1.70	2.35	3.41	3.98
La Crosse	1.09	1.05	1.57	2.36	3.61	4.45
Mean	.80	.82	1.42	2.24	3.17	4.13

	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Duluth	3.75	3.44	3.67	2.71	1.53	1.26	29.98
Moorhead	3.93	3.10	2.23	2.09	.92	.67	24.60
Bismarck	2.20	1.97	1.19	1.03	.67	.61	18.14
St. Paul	3.48	3.68	3.28	2.41	1.24	1.09	28.42
Minneapolis	4.14	3.83	3.39	2.71	1.12	.93	28.65
La Crosse	4.04	3.49	4.03	2.50	1.47	1.31	30.83
Mean	3.59	3.25	2.96	2.24	1.16	.98	26.77

[a] From records compiled by U. S. Weather Bureau, Washington, D. C.

There is a period of heavy rainfall from May to September, inclusive. The precipitation is generally least in January, during which month it does not often exceed one inch. During the period of greatest precipitation there are frequent heavy rainstorms, which in the deforested and prairie regions cause the streams to rise rapidly. Snow falls in every part of the region. The average annual fall is 40 inches of dry snow, most of which is precipitated in the region around Lake Superior, though the severest blizzards, during which there is the greatest precipitation at one time, occur in the western part of Red River Valley. The heaviest storms occur generally during December and March. The precipitation during the later part of the winter causes heavy floods in the spring, for the rapid melting of the snow on the ground after the spring rise in temperature coincides with the heavy rains of April and May.

SUMMARY.

At many points throughout the region under consideration voluntary observers record the temperature and the precipitation. Unfortunately these records have not been continued long enough to furnish data for reliable deductions concerning the general weather conditions of each drainage area. Therefore the following figures, representing averages made from the records of 36 stations in Minnesota, North Dakota, and Wisconsin may be subject to change as further data are recorded.

TABLE 7.—*Mean annual temperature and precipitation.*[a]

Area.	Temperature.	Precipitation.
	Degrees F.	*Inches.*
Superior	39	30
Upper Mississippi	41	27
Minnesota	43	26
Lower Mississippi	45	31
St. Croix	41	30
Red	39	22

[a] Computed from records given in Ann. Repts. of Chief of Weather Bureau, 1892-1904, inclusive.

In general the climate of Minnesota is typical of the central part of the temperate zone. Since there are no high mountains to protect the State, it is exposed to the cold winds of Canada and to the warm waves of the lower Mississippi Valley. The treeless plains of its western section experience the greatest extremes of temperature and receive the least rainfall. The region around the Great Lakes has the least variation of temperature and a high total precipitation. There is measurable precipitation on about ten days in each month in every part of the area; and the year can not, therefore, be divided into a rainy and a dry season. To this even distribution of the rain throughout the warmer half of the year this section owes its remarkable fertility and its adaptability to many kinds of crops. The ground freezes in November and thaws in the latter part of March or the first of April. During the period of low temperature the rivers and lakes throughout the State are frozen. In the spring heavy rains accompany the rise of temperature that causes the melting of the accumulated snow and ice.

The following table summarizes the important weather conditions in the region considered:

TABLE 8.—*Summary of weather conditions in the Minnesota region.*

Station.	Temperature, °F.		Precipitation in inches.		Dates for severe frosts.	
	Mean.	Range.	Average total.	Average snowfall.	Fall.	Spring.
Duluth	39	117	29.98	54	Oct. 4	May 3
Moorhead	38	125	24.60	38	Sept. 22	May 14
Bismarck	40	132	18.14	34	Sept. 15	May 15
St. Paul	44	119	28.42	38	Oct. 5	May 6
Minneapolis	45	119	28.65	40	Sept. 30	May 2
La Crosse	46	117	30.83	39	Oct. 5	May 1
Entire area	42	122	26.77	42	Sept. 28	May 7

GEOLOGIC FORMATIONS AND SOILS.

Probably no other natural feature has more profound influence on the character of surface waters than the chemical composition of the rocks over or through which they flow. At all seasons of the year a certain percentage of the stream flow above ground is derived by

epage from the water-bearing strata that outcrop along the banks the rivers and in lake bottoms. In winter, when the surface of the ound is frozen and there is no surface drainage, the stream supply, cept that which is produced by irregular and intermittent thaws, is rived from underground water. Therefore the nature of the geogic formations and the character of the water contained in them are nportant features to be considered in a study of surface waters. he soil and the subsoil also have great influence on the character of ie water of streams and lakes, because rain water dissolves more or ss of the soluble soil constituents and is thus modified in its chemical omposition before it finds its way to the water courses.

GEOLOGIC FORMATIONS.

Geologically, Minnesota may be divided into three sections: (1) A ortheastern division, embracing the districts adjacent to Lake Supeor; (2) an eastern and southeastern division, reaching, with one ight interruption, from the head of Lake Superior southward into owa, and (3) a western district, embracing the remainder of the tate.[a]

The northeastern division, embracing the Mesabi and Vermilion on-bearing districts, includes the Laurentian basin and that part of ainy River drainage area that lies directly north of it. The formaons are mainly crystalline, consisting of quartz, gneisses, schists, and ther igneous and metamorphic rocks. There are valuable outcrops f these earlier formations at St. Cloud and in the area northeast of iat city.

At many places along Minnesota River the bed of the stream is ranite in place. The ore deposits in the iron districts contain large uantities of water, which, on one hand, embarrass miners, and, on the ther, afford water supplies for neighboring municipalities. None of iese rocks except the ore deposits transmits much water. The early ormations are covered by a deposit of drift, of variable thickness, hich affords a supply of water for shallow wells.

The eastern and southeastern division, extending from Lake Supeor to the Iowa boundary, is underlain by Cambrian and Ordovician ocks. The belt comprising these formations gradually widens oward the east and west in its extension southward from the northern ction of this region, in upper St. Croix valley. These rocks consist f a succession of sandstones, shales, dolomites, and dolomitic limeones, of variable thickness, which dip generally southward. The west water-bearing stratum is the basal sandstone, sometimes cally known as the "Potsdam." This is overlain by a succession of iales and dolomites called the "St. Lawrence formation," above

[a] Hall, C. W., Hydrology of Minnesota: Water-Sup. and Irr. Paper No. 102, U. S. Geol. Survey, p. 441.

which lies in turn the "Jordan" sandstone, a strong artesian bed over 100 feet thick. The next rock containing water is the New Richmond sandstone, of variable thickness and locally absent, which is separated from the "Jordan" below by the Oneota limestone ("Lower Oneota"). The St. Peter sandstone is separated from the New Richmond by the Shakopee limestone ("Upper Oneota"). Both the Oneota and the Shakopee are beds of impervious dolomite and contain no water. The St. Peter sandstone is a strong water-bearing body, of varying thickness, extending from the region around St. Paul continuously southward beneath the surface through the State of Iowa, where it affords a supply for many artesian wells. It is covered by an impervious limestone which has been classed as the "Trenton-Galena."

The western division includes the upper part of Minnesota River Valley, all of Red River Valley, and part of upper Mississippi Valley. It is covered by rocks of the Cretaceous system, named in succession,[a] beginning with the earliest, the Dakota, Benton, Niobrara, and Pierre formations. These consist, respectively, of sandstone of considerable thickness containing a few scattered beds of shale and lignite; alternating shales and clays with some limestone; calcareous marl blending into the limestone of the Benton; and shales and clays, sandstones, and sandy shales. The Dakota sandstone is the source of the supply of the famed artesian basin of the Dakotas. The Cretaceous beds overlie Archean and Algonkian rocks in an area in the northern part of Minnesota that extends as far east as Allen Junction, south of the Mesabi range, and cover Cambrian and Ordovician rocks in the southwestern part of the State. Deposits of drift lie at the surface throughout the State of Minnesota except in a comparatively small area in its southeast corner that forms a part of the "Driftless Area," which comprises portions of Minnesota, Wisconsin, Iowa, and Illinois. The Pleistocene deposits vary considerably from place to place in thickness and character, and the waters they contain are therefore more variable chemically than those that occur in the lower rocks.

Waters derived from the Cretaceous rocks are strongly alkaline, and the fact that they contain many saline deposits is shown by the character of the water coming from some portions of Red River Valley. Waters obtained from the sandstones in the eastern part of the State are much less strongly mineralized than those coming from the sandstones of the western part, though their hardness is influenced by contiguous limestones and dolomites. Waters from the older rocks naturally show the least mineralization, and waters from the ore bodies in the iron ranges do not contain ingredients that make their economic use undesirable, such as appear in mine drainage in many other sections of the country.

[a] Upham, Warren, The Glacial Lake Agassiz: Mon. U. S. Geol. Survey, vol. 25, pp. 81-82.

SOIL AND SUBSOIL.

Four distinct kinds of subsoil are found within the State:[a] (1) Blue till, (2) red till, (3) gravel and sand, (4) clay or clay loam. These different kinds of soil owe their general characteristics to contiguous earlier formations, and these characteristics in turn determine or influence the condition of the soil and the drainage in the region where each predominates.

The blue till, derived principally from the disintegration of rocks of the Cretaceous formations, is strongly impregnated with salts of the alkalies and of the alkaline earths. The prairie part of Minnesota is characterized by soils of blue till, except in parts of Red River Valley, where the soils are derived from lacustrine clays, and in a few places where they are derived from loess loam. These soils correspond, in general, to the section of Cretaceous rocks, though their alkaline content decreases toward the east as they become modified by the minerals of other systems.

The red till contains a large amount of iron oxide, practically no alkaline salts, and somewhat less alkaline-earth compounds than the blue till. Red-till subsoils extend from the northeast corner of the State southwestward to St. Paul, where they begin gradually to blend into the blue-till subsoils of the western portion of the State and the clay loams of the Driftless Area.

The gravel and sand subsoils consist of modified till, their local character being determined by the character of the till in the regions where they occur. They are abundant in parts of the morainic deposits known as the Leaf Hills.

Clay or clay-loam subsoils were deposited from the great sheets of fresh water that once covered large sections of the State. They owe their predominating characteristics to the character of the tills from which they were derived, but contain much less alkaline material. They appear throughout the lower part of Red River Valley. Clay-loam subsoils are also found in lower Mississippi Valley and in the lower section of St. Louis Valley.

ECONOMIC DEVELOPMENT.

POPULATION.

The rapid increase of population in Minnesota is a most important element to be considered in studying the resultant inevitable increase in the pollution of its lakes and streams. Before the first quarter of the nineteenth century the region was practically an unsettled wilderness, containing only a few scattered trading posts belonging to the Hudson Bay Company. In 1819 a military reservation, now known

[a] Winchell, N. H., Final Rept. Geol. and Nat. Hist. Survey Minnesota, vol. 1, pp. 125-128.

as Fort Snelling, was established by the United States Government at the confluence of Minnesota and Mississippi rivers. Settlement has steadily progressed from that time to the present. Prairie land of great fertility, easy of access by water, attracted pioneers from all over the world. At the end of 30 years it was deemed advisable to set apart from Wisconsin the territory of Minnesota. In 1858 the State of Minnesota was admitted to the Union. The following table, giving the population for the area now included within its boundaries, shows how rapidly the increase has taken place:

TABLE 9.—*Total population of Minnesota from 1850 to 1905.*[a]

Census.	Population.	Per cent increase.	Inhabitants per square mile.
1850	6,077	.....	0.03
1860	172,023	2,730.7	2.2
1870	439,706	155.6	5.6
1880	780,773	77.6	9.9
1890	1,301,826	66.7	16.5
1900	1,751,394	33.8	22.1
1905	1,979,912	[b]13	25

[a] Figures for 1850-1900 are from U. S. Census; those for 1905 are from State Census.
[b] Percentage increase in five years.

At the time of the first official census, taken soon after the organization of the Territory, the population was concentrated in the region lying within a few miles of St. Paul and in a settlement on Red River in Pembina (now Kittson) County. Between 1850 and 1870 there was an enormous influx of settlers to the southern and central parts of the State. Since that time the percentage of increase has been always considerably higher than the average for the rest of the United States. The number of inhabitants per square mile is rapidly increasing. In spite of this growth, however, the State is still a pioneer country. Its density of population is little more than half that of the general average for the basin of Mississippi River, the most thickly settled portion is still in the region near St. Paul and Minneapolis, while in the Rainy River drainage area the population is considerably less than one person per square mile, and many townships are practically uninhabited. That this region will not long remain in its present unsettled condition is shown by the constant migration to it. The prospective removal of forests and the drainage of swamps will undoubtedly result in the establishment of farms with their attendant trading centers and, from a sanitary standpoint, other foci of pollution.

PRINCIPAL INDUSTRIES.

AGRICULTURE.

The chief reason for the progress and development of the State in general has been the abundance of inexpensive land remarkably well suited to the cultivation of cereals.

TABLE 10.—*Chief agricultural products in Minnesota, 1899.* [a]

	Bushels.
Wheat	95,278,660
Corn	47,256,920
Oats	74,054,150
Potatoes	14,643,327

At present Minnesota is the greatest wheat-growing State in this country, about 12 per cent of its area producing that crop. Corn is extensively raised in the southern tier of counties, along the Iowa line. Oats, barley, rye, and potatoes are also largely cultivated. Red River Valley west of Thief River Falls and Minnesota River drainage area and the territory south of it, or about 40 per cent of the total area of the State are prairie lands with rich soil, requiring small investment for the production of large crops. Upper Mississippi Valley below Brainerd, now practically deforested, contains many farms. As soon as the northern counties are cleared of their timber it is probable that the entire section will become wheat-raising farms, similar to the part now under cultivation.

LUMBERING.

One of the greatest attractions in Minnesota for explorers and settlers was the great wealth of timber, principally white pine. Originally a line extending from Thief River Falls southeastward to the mouth of St. Croix River would have marked the southern boundary of the great pine region, along the edge of which stretched a belt of hard-wood forest 50 to 100 miles wide. At present the greater part of the standing timber is in the northern region, in Beltrami, Itasca, St. Louis, Lake, and Cook counties, and on the Indian reservations. St. Louis, St. Croix, and Mississippi rivers, the principal outlets for the lumber, afford easy access to sawmills and cheap conveyance for the sawed material. The amount of organic matter introduced into these streams and their tributaries by reason of the lumber industry is an important factor in the consideration of the value of surface water from the forested regions. A greater or less number of logs at all seasons of the year are floated in the rivers and lakes, which dissolve the resinous matter. Sawdust from the mills is a serious source of stream pollution. The total amount of lumber cut in Minnesota during 1899 was 1,934,157,000 feet B. M., which is a fair average for the cut from year to year. From 500,000,000 to 700,000,000 feet are cut annually on the upper Mississippi alone and this enormous industry will continue until the pine forests of the State have been exhausted. The result of this removal on the quality and amount of surface water can not be predicted.

[a] Twelfth Census U. S.

COMMERCE.

The principal trading centers of Minnesota are Duluth, Minneapolis, and St. Paul. The first of these, situated at the head of Lake Superior, owes its importance principally to its enormous traffic in iron ore, which is received by rail from the Mesabi and Vermilion districts and shipped across the Great Lakes. It is also a shipping point for grain and lumber and has a large import trade. It is the center of commerce for the northeastern part of the State and has considerable through traffic with the Pacific coast.

TABLE 11.—*Chief shipments by water from Duluth, 1903–5.*[a]

Product.	1903.	1904.	1905.
Grain.....bushels..	11,229,703	11,560,083	16,938,50
Lumber.....feet B. M..	355,712,000	344,109,000	357,814,000
Iron ore.....gross tons..	5,362,731	4,342,782	8,731,27

[a] Monthly Summary of Commerce and Finance, Bureau of Statistics, Department of Commerce and Labor, December, 1904, pp. 906–907; December, 1905, pp. 706–721.

Minneapolis owes much of its growth to the water power of St. Anthony Falls, by means of which this city has developed the largest flour mills in the world. Its principal trade is in wheat and lumber; it is a distributing point for all sorts of manufactured products throughout the Northwest.

St. Paul, at present the head of navigation on Mississippi River, is the transfer point of a great transcontinental traffic. It has a large commerce in lumber, live stock, and general merchandise. Regular lines of steamers run from St. Paul to lower ports on Mississippi River, and a considerable traffic is carried on by other vessels. Lumber is floated in enormous rafts down Mississippi River to St. Louis and other southern ports.

Besides the three cities above mentioned, points of minor commercial importance are: Winona, a distributing point for southeastern Minnesota; Mankato, the metropolis of Minnesota Valley; Fergus Falls, on Ottertail River, and Crookston, which has a large trade in wheat, lumber, and agricultural implements.

MINING.

Iron is the only metal that is extensively mined in Minnesota. The discovered deposits are included almost entirely within St. Louis County, north of Duluth. The Mesabi district, which extends generally northeast and southwest across the county and forms a great part of the north boundary of St. Louis River basin, was opened in 1892 and quickly became the largest ore-producing district in the Lake Superior region. In 1904 the output of this one district alone was over 40 per cent of the total production in the United States.

North and somewhat east of the Mesabi range is the Vermilion iron-earing district, which was opened in 1884. Its annual output is om one million to two million tons of ore.

TABLE 12.—*Production of iron ores in Minnesota, 1899–1904.*[a]

[Long tons.]

Year.	Vermilion range.	Mesabi range.
1899	1,643,984	6,517,305
1900	1,675,949	8,158,450
1901	1,805,996	9,303,541
1902	2,057,532	13,080,118
1903	1,918,584	13,452,812
1904	1,056,430	11,672,405

[a] Birkinbine, John, The production of iron ores in 1904: Mineral Resources U. S. for 1904, U. S. Geol. Survey, 1905.

On account of the structure of the ore deposits, water traverses them readily, so that wherever mining is done the water must be removed. The use of mine water in this section does not present serious troubles from an industrial standpoint. The amount of dissolved solids it contains is comparatively small, though it varies considerably, depending upon the length of time it has been in contact with the underground strata. The rapid development of this enormous industry, however, has more bearing on the resultant stream pollution by the constantly increasing population. In 1880 the total population of St. Louis County was 4,504. North of Duluth lay a wilderness that was invaded only now and then by lumbermen. With the opening of the Mesabi range there was a sudden influx of prospectors and miners to this region and towns sprang up there as if by magic. In 1890 the population of the county, excluding Duluth, was 11,746; in 1900 there were nine settlements in the iron districts, having a population exceeding 1,000, and the total number of inhabitants in the county had doubled in ten years; in the period from 1900 to 1905 the total population increased by more than 35,000. With this rapid growth concentrated in mining towns, there was neglect of sanitary precautions and a disinclination to heed the experience of similar settlements elsewhere. Sewerage systems were constructed only after harsh lessons. Water supplies were taken in the least expensive way from the most convenient sources, generally from mine sumps or small creeks. An inevitable result of this disregard for hygienic measures was the occurrence of severe epidemics of typhoid fever.

WATER-BORNE DISEASES.

GENERAL DISCUSSION.

The value of water as a municipal resource is greatly affected by its liability to transmit disease from one locality to another. Until recently the belief was more or less general and even yet the opinion is not entirely eradicated, that the danger of water lies in part in "miasmatic vapors" or "fever fogs," which may affect those who breathe the air in the vicinity of swamps or other stagnant water. This paludal or miasmatic poison, vague or indeterminable in its origin and character, was believed to be the direct exciting cause of malaria or ague and even of other febrile humors, and was supposed besides to favor the spread of contagions and epidemics in general. More certain knowledge has gradually been gained concerning the cause, the means of spread, and the methods of preventing disease, and it is now known that water may carry living organisms or other substances that produce disease. Chemical substances when dissolved in water may act in a toxic or poisonous way. Even comparatively pure water, especially soft water, may prove dangerous by reason of its solvent action upon lead pipe if that is used for its transmission. Biological and clinical studies have determined beyond doubt the relationship of marshy districts to such diseases as malaria and yellow fever. It is now well known that the danger from swamps is due to the facilities which they afford mosquitoes for breeding, since the virus of these two diseases, and probably also of filariasis, is transmitted by mosquitoes. In passing, it may be stated that two methods of protecting the public health should be combined—namely, the extermination of mosquitoes of certain or all varieties and the protection of the sick from mosquito bites.

Sanitarians are justly concerned with a certain group of water-borne diseases, of which typhoid fever, cholera, and possibly certain diarrheal diseases are types. The infecting bacteria in these diseases may live for some hours or days in water. Certain of these diseases, particularlyty phoid fever, are so prevalent in this country that in almost every community there are some infected persons whose dejecta carry pathogenic germs. Since there is so much difference in the relative resistance of individuals to infective organisms, it frequently happens that patients who are suffering from the disease are not aware of it, nor are their friends. Furthermore, the long persistence of the infecting micro-organisms of typhoid fever in the body of the patient, particularly in the urine, makes the infection of sewage very easy, and since the same care is not exercised in the disposal of the urine as of the feces, water supplies and milk or foodstuffs may easily be infected either directly or from the hands. Water

ito which sewage is discharged becomes, therefore, a vehicle for ansmitting diseases from one place to another, and the germs of ifection are therefore called water borne.

TYPHOID FEVER.

CAUSE AND PREVALENCE.

Of the diseases which are transmissible by water, typhoid fever ierits special attention in Minnesota and in other newer communiies. In Massachusetts, where the conservation of water supplies and he proper disposal of sewage have received attention for many years, nilk-borne epidemics are more to be considered than in Minnesota. Even milk-borne epidemics, though they are perhaps most usually lue to the fact that a typhoid patient or an attendant upon a typhoid atient is engaged in handling milk, may be spread by means of water when the infecting organism gains entrance to a water supply which s used for cleansing utensils or, in very rare instances, where the outside of the udder and teats of the cow are contaminated by sewage containing typhoid bacilli. There can now be no reasonable doubt that *B. typhosus*, the specific organism of typhoid fever, can exist for a considerable period of time in water. The studies of Jordan, Russell, and Zeit would seem to show that the organism dies in ordinary running water in three to eight days, but the difficulty of exactly reproducing natural conditions in the laboratory permits only very guarded conclusions from such experiments.

The relationship of typhoid-polluted sewage to outbreaks of the disease has been clearly demonstrated in this country at Plymouth and Butler, Pa., Ithaca, N. Y., and many other places. In Minnesota, as in other new regions which are being settled rapidly, typhoid fever is more or less prevalent and is one of the chief causes of death in the State. New communities are usually established with more regard to financial advantages than to sanitary conditions. The careful disposal of excreta and the selection and protection of safe water supplies and other hygienic improvements are neglected until their necessity is shown by costly epidemics. Even then, unless action is taken during the progress of an epidemic the matter is likely to be neglected, since the general interest in projects affecting the public welfare is likely to wane unless private stimulation be applied.

The principal settlements in Minnesota are on the shores of lakes or on the banks of running streams, to which the towns have recourse both for their domestic supply and for the disposal of their sewage.

Since 1887, when the care of vital statistics was transferred to the State board of health, the statistics of deaths from typhoid fever have been carefully compiled. Undoubtedly a considerable percentage of

the typhoid mortality has not been recorded on account of neglect to report from all parts of the State and also on account of diversity of diagnosis. Whether the death rate from typhoid fever in Minnesota is lower than that in Massachusetts, New York, and other States cannot be definitely affirmed, but it would appear that the disease is very much less virulent in Minnesota and the Dakotas. From observations made by competent clinical men during severe local epidemics it appears that the death rate as compared with the case rate is between 2 and 4 per cent. This low rate may be due to the diagnosis of cases as typhoid fever in Minnesota which would not be so classified in other communities. The Widal blood test is very extensively used throughout the State by private practitioners and by hospitals, and this test is made gratuitously by the State board of health and by the local boards of health of Minneapolis and St. Paul. This confirmatory examination probably results in the return of cases as typhoid fever which ordinarily would not be so classified.

The records of deaths received since 1888 are as follows:

TABLE 13.—*Deaths from typhoid fever in Minnesota per 100,000 population.*[a]

Year.	Entire State.	Cities exceeding 5,000.	State, excluding cities over 5,000.
1888	53.63	114	30
1889	45.7	76	32
1890	30.8	52.2	25
1891	39.23	64.8	28
1892	28.6	47.5	21
1893	38.5	63.0	27
1894	35.2	57	26
1895	35.9	57.3	27
1896	27.8	51.6	17.7
1897	25.7	50	15.5
1898	22.6	37.2	16
1899	18	30.4	12.8
1900	32.6	43.0	28.0
1901	26.0	41.8	19.3
1902	21.21	29.73	15.93
1903	19.9	32.7	14.2
1904	18.68	33.2	13.4
1905	14.6	22.0	11.2

[a] From the official records of the secretary of the State board of health. The population of the cities considered above is estimated by adding the average annual increase as shown by the United States and the State censuses to each preceding year.

The village and rural death rate from typhoid fever, shown by the fourth column, is much lower than the urban rate, but comparison of the second and fourth columns indicates that typhoid fever is extremely prevalent in rural districts. Allowance should be made for the fact that since the better hospitals are located in the large centers many serious cases of all forms of illness are taken to them from outlying districts, a factor which would disproportionately increase the total death rate for the cities. This is particularly true of Duluth, to which the settlements of the iron-bearing districts are tributary. Typhoid fever has been prevalent in these mining communities for a

number of years, and since many cases are brought to Duluth the statistics of deaths from the disease in that city are thus greatly increased. In the smaller communities a difference of one or two deaths makes an enormous difference in the rate per hundred thousand.

These records show that there are from 300 to 800 deaths from typhoid fever in Minnesota every year. Assuming a ratio of 1 to 25[a] between the number of deaths and the number of cases, it would appear that approximately from 7,500 to 20,000 people are stricken annually with this disease, which can be and should be prevented. The official records show that from 1891 to 1900, inclusive, 4,532 persons died of typhoid fever in Minnesota.

In May, 1905, reports were made by the health officers of 166 settlements in the State in reply to the following questions:

1. During 1904 how many cases of typhoid fever occurred in your city?
2. How many cases of the disease in the city were personally seen by you?
3. How many other cases in the city were reported to you?
4. How many cases in the city were probably not reported to you?

According to these records and the official reports of Duluth, Minneapolis, and St. Paul, there were in Minnesota 1,062 cases of typhoid fever during the year 1904, but from other means of checking and by mathematical reckoning it seems probable that there were from five to ten times as many cases as were reported. As bearing upon this, it may be stated that in three months two towns situated on Red River—namely, Breckenridge, Minn., and Wahpeton, N. Dak., with a total population of 4,090—developed 200 cases of typhoid fever.

The highest mortality from typhoid fever occurs during October and the lowest during April, May, and June. During the summer months the death rate from this disease rises rapidly to its maximum in October and falls as rapidly. The average typhoid-fever death rate per hundred thousand for the entire State is 29.43, a little lower than the rate for the registration area (33.8), according to the Twelfth United States Census.

EPIDEMICS.

Hardly a community in Minnesota has escaped one or more epidemics of typhoid fever. Duluth suffered from a series of outbreaks which culminated in 1896. Investigation showed that the intake of the waterworks system, which was supposed to extend a considerable distance into Lake Superior, was defective, and that the water supply was being contaminated with more or less dilute sewage at a point within 300 feet of the outlet of one of the principal sewers. Repair of this defect and extension of the intake to Lakewood, 8 miles nearer

[a] In Massachusetts and older communities the death rate is about 10 per cent; that is, from two and one-half to four times as great as in Minnesota.

the main lake, has practically wiped out the disease, for the cases that have occurred since then are imported or are due to the use of infected well water or to the result of contact with imported or such local cases. The water supply at present seems to be satisfactory.

The largest epidemic of typhoid fever in Minneapolis occurred in 1881 and 1882, during which time there were 350 deaths. There was another serious outbreak in 1897, when there were 1,534 cases and 148 deaths. The disease has always been prevalent in the city, where several other well-marked epidemics have occurred, which have been attributed to the use of unfiltered river water.[a] Minneapolis has the unenviable distinction of having recorded nearly 50 per cent of the total deaths from typhoid fever in Minnesota during the past decade,[b] although its population is only a little over one-tenth of that of the State.

In 1898, while the United States Volunteers were encamped at the State Fair Grounds (Camp Ramsey) and at Fort Snelling, 40[c] cases of typhoid fever were reported for the Fifteenth Regiment Minnesota U. S. Volunteers, 346 of which occurred before its departure for Camp Meade, Pennsylvania.[c] A detailed account of the fever in this regiment is given in the special report of the Surgeon-General of the U. S. Army on typhoid fever among the volunteer regiments during the Spanish war of 1898.

As stated above, settlements in the mining districts of St. Louis County have been subject to typhoid fever, and notable epidemics have occurred at Eveleth, Hibbing, and Virginia, all of them probably due to impure water supplies.

IMPROVED CARE, CONTROL, AND REPORT OF TYPHOID FEVER.

Section 2131 of the Revised Laws of Minnesota, 1905, authorizes the State board of health of Minnesota to adopt, alter, and enforce reasonable regulations, which, after the approval of the attorney-general and due publication thereof, have the force of law, except in so far as they may conflict with a statute or with the charter or ordinances of a city of the first-class upon the same subject. In accordance with the authority thus delegated and upon realizing that Minnesota was suffering from a disease which is strictly preventable, the State board of health passed certain rules on the 14th day of July, 1906. Rules 45 to 54 deal with typhoid fever and may be quoted as follows:

RULE 45. Every physician engaged in the practice of medicine in the State of Minnesota shall submit to the secretary of the State board of health the full name, specific residence, and hygienic data, on blanks furnished by said board for that pur-

[a] Rept. special commission appointed by the city council to investigate the Minneapolis water supply, 1904; also Corbett, Dr. J. F., Typhoid and water supply: Ann. Rept. Dept. Health, city of Minneapolis, for 1904, pp. 27–28.

[b] Public Health Reports, Public Health and Marine Hospital Service, Treasury Dept.

[c] Rept. Minn. State Board of Health, 1895–1898, p. 472.

pose, of every person under his treatment for typhoid fever or suspected typhoid fever, within one week after the application of such patient for treatment.

Physicians in cities and villages where they are required by ordinance or sanitary regulation to report typhoid fever cases to the local board of health will not be required to report such cases directly to the State board of health, provided the local health officer makes returns of all cases reported to him to the State board of health once a month on blanks furnished for that purpose by said board.

RULE 46. The secretary of the Minnesota State board of health shall keep a careful and accurate record of all reported cases of typhoid fever. The same shall not be for publication, but may be used by said board in the discharge of its duties.

RULE 47. Immediately after being notified of any case of typhoid fever the secretary of the Minnesota State board of health, or the local health officer, shall send to the address of the attending physician the printed matter published by the State board of health relative to the control of typhoid fever. Such physician shall thereupon deliver the same to those in charge of the patient.

RULE 48. No person affected with typhoid fever, or in charge of a typhoid fever patient, shall so dispose of the excreta or other infectious bodily secretion or excretion as to cause offense or danger to any other person or persons.

RULE 49. Any health officer receiving a complaint that the foregoing rule is being violated shall investigate the same, and if it appears that the violation complained of is such as to cause offense or danger to any person he shall serve notice upon the offending party, reciting the alleged cause of offense or danger and requiring that the bodily secretions or excretions complained of be disposed of in such a manner as to remove all reasonable cause of offense or danger.

RULE 50. It shall be the duty of those having charge of a typhoid fever patient or patients to see to it that the excreta, or other infectious bodily secretions or excretions, from such patients are properly disinfected.

RULE 51. The apartments occupied by any typhoid fever patient shall be deemed infected, and when vacated by death or removal of the patient shall, together with their contents, be thoroughly disinfected under the supervision of the local health officer. All disinfection prescribed in this rule shall be a part of the control of the disease.

RULE 52. It shall be the duty of any person having knowledge of the facts to notify the local health officer within twenty-four hours after the death or removal of a person affected with typhoid fever from any apartments.

RULE 53. Whenever typhoid fever prevails in a locality the local board of health shall immediately appoint a competent inspector or inspectors to patrol the city, village, or district involved. Such inspector or inspectors shall report to the local board of health all water-closets, privies, vaults, and cesspools which are not fly proof, with screened doors and windows; and all vaults and cesspools which are not water-tight, dark, and fly proof. The local board of health shall thereupon enter its proper order in the premises to the end that all such water-closets and privies shall be made fly proof, and all such vaults and cesspools water-tight, dark, and fly proof.

RULE 54. Any drinking-water supply shown to be a positive or probable source of disease shall be condemned either by the local board of health or by the Minnesota State board of health, and when so condemned, shall not be used again as a drinking-water supply until declared safe by the condemning party.

A blank to be used by physicians and health officers for reporting cases of typhoid fever has been prepared in the form of a card, the two sides of which are here reproduced:

REPORT OF A CASE OF TYPHOID FEVER.

Name in full ——— ———.

(Be specific in answering the following three questions, giving name of street, house number, or other definite statement, such as name of farm, camp, mine, etc., in order that the patient may be definitely located.)

Age ———. Sex ———. Occupation ———.
Residence when taken ill ———.
Place where employed when taken ill ———.
Present address ———.
First taken sick with typhoid fever: Year ———. Month ———. Day ———.
First seen by a physician: Year ———. Month ———. Day ———.
Name and address of first attending physician ——— ———.
Total number of people living in house when patient was taken ill ———.

[Reverse side.]

Where was patient living during the three weeks before illness began? ———.

(Name all places, with date of residence at each place.)

Are any intimate associates of patient sick with typhoid fever? ———.

(Father, mother, child, brother, sister, husband, wife, fellow boarder, etc.)

If so, give present address of such associates ———.
Source of milk used by patient ———.

(Name and address of milkmen.)

Source of drinking water used by patient before illness began ———.

(Name and location of well, stream, lake, or other water source.)

Present status of case: (Still sick; recovered; convalescing; dead).
Physician's view of source of infection ———.
Filled out by Dr. ——— of ———, Minn.
Date of report ———, 190—.

One of the chief difficulties in the control and arrest of typhoid fever is the failure on the part of local authorities to realize that it is preventable and to make a careful canvass of the localities for the purpose of obtaining accurate data, such as that required in the above blank.

The State board of health is frequently asked to make examinations of water as a basis for action or recommendation in a given locality when no data are available to show which, if any, water is the cause of disease. It is hoped that the habit of securing full and accurate data will result in the education of the people of the State at large concerning the various vehicles of infection in typhoid fever and the means of arresting it.

A notice similar to the following should prevent the spread of typhoid fever pending the determination of the exact cause of the disease. The wording of this notice was suggested by Dr. H. W. Hill, assistant director of the laboratories of the Minnesota State board of health, and has been found very efficient.

TO THE CITIZENS OF ——.

Typhoid fever is epidemic in ———. The Minnesota State board of health is investigating this epidemic to find its exact source. Meantime govern yourselves as follows:

1. Typhoid fever is contracted solely *through the mouth*. If you do not put the poison of typhoid fever into your mouth you will never contract typhoid fever. Therefore, *watch the mouth*.

2. Do not eat or drink anything (water, milk, oysters, fresh vegetables, or anything else) unless it has first been boiled, broiled, baked, roasted, fried, or otherwise thoroughly heated through and through.

3. Do without all food or drink which has not first been thus heated. Canned or bottled foods or drinks (other than milk or water) are not included in this.

4. If living in the same house with a typhoid patient, do not handle your own food or food intended for anyone else, even if it has been heated, except with hands that have been thoroughly washed with soap and very hot water; preferably also with antiseptics. (Ask your physician about the antiseptic to use.) Wash before every meal in this way and before cooking, serving, or eating anything or putting the fingers in the mouth.

5. If there are flies, roaches. or other insects or vermin about, see that all food and drink is protected from them at all times. Flies and other insects often carry typhoid poison to foods and drinks.

6. The poison of typhoid fever does not show itself for *two weeks* after it enters the body. Therefore for the next two weeks typhoid cases may develop from typhoid poison already taken in; but any case which develops on and after (a date two weeks later than the date of the placard) will be due solely to neglect of this notice and failure to carry out minutely the directions here given.

OTHER WATER-BORNE DISEASES.

There is no evidence that there are any other important water-borne diseases in Minnesota. It is possible that hog cholera among animals should be considered in the category.

STREAM POLLUTION.

SEWAGE.

Fifty-seven settlements in the State are more or less completely equipped with sanitary sewerage systems. Most of the cities in the State are situated on flowing streams, which are thus convenient receptacles for city sewage. In 1885, recognizing the fact that this would result in dangerous pollution, the State legislature passed a law entitled "An act to prevent the pollution of rivers and sources of water supply,"[a] which prohibits the discharge of sewage, drainage, refuse, or other polluting matter dangerous to health into any surface waters used as a source of municipal supply. The act also gives the State board of health supervision over all municipal water supplies and the power to institute legal proceedings against violators of the statute. Notwithstanding the provisions of this law, sewage-purifica-

[a] Chapter 225, secs. 1-7, laws of 1885, approved March 7, 1885.

tion plants have not been generally established in the State, so that stream pollution has not been materially checked. At the State hospital for the insane at Rochester a system of precipitation and filtration was put into operation in 1890. Improvements are contemplated. In 1904 a purification system consisting of a septic tank combined with contact and intermittent sand filters was installed at the State insane asylum at Anoka. A few villages have made unsuccessful attempts to comply with the requirements of the statute by establishing sewage-purification plants. The large cities, however, without exception, discharge raw sewage into adjacent bodies of water.

INDUSTRIAL WASTES.

Dangerous effluents from manufacturing establishments are not yet of serious importance in Minnesota. In the spring of 1905 inquiry was made to ascertain to what extent manufacturing wastes cause stream pollution. From replies received from 174 municipalities the following list has been prepared:

TABLE 14.—*Industrial establishments causing stream pollution.*

Industry.	Establishments.	Industry.	Establishments.
Breweries	73	Slaughterhouses	24
Creameries	138	Soap works	8
Dyehouses	13	Starch factories	8
Gas works	14	Sugar factory	1
Paper mills	6	Tanneries	12
Rendering works	19	Woolen mills	12
Sawmills	98		

From this table it appears that there are in the State few factories that emit deleterious wastes. With the exception of the sawmills the establishments noted are generally small. Though probably some establishments were not reported because they are located outside of organized villages or cities, yet the list represents with fair accuracy the possible foci of pollution from industrial wastes. The kinds of plants whose wastes cause so much trouble in other sections of the country are either small or are entirely absent. No bleacheries, cotton mills, distilleries, galvanizing works, nitroglycerin factories, petroleum refineries, strawboard mills, or tin-plate works were reported from any part of the State. The effluents from the majority are not discharged directly into streams, but are either consumed or decomposed on the ground. In comparison with large manufacturing centers in the East, stream pollution by industrial wastes is an insignificant factor in Minnesota.

The trouble from sawmills is caused by three different classes of waste: First, by organic matter dissolved in the water from the logs

which lie in the lakes and streams from the time they are run till they are sawed; second, by excreta from the lumbermen themselves, who are constantly in the water for the purpose of sorting and guiding the logs; third, by sawdust and other minute waste. The latter cause of trouble is the most evident one, and has the effect of forming nuclei for the growth of organisms and of obstructing the free flow of the water. In reports of the U. S. Engineering Corps it is stated that many of the bars in Mississippi River above Lake Pepin are composed largely of sawdust and that the material has been found by dredging as far south as Winona.[a] It is evident that the distribution of this material over the beds of streams is anything but favorable to the hydrolysis of other more dangerous pollutions, and in view of the fact that it has a certain commercial value, this disposal of it seems not only unsanitary, but wasteful.

MISSISSIPPI RIVER BASIN ABOVE MINNESOTA RIVER.

GENERAL DESCRIPTION.

BOUNDARIES.

Mississippi River basin above Minnesota River is bounded on the east by St. Louis and St. Croix drainage areas; on the north by Rainy River basin; on the west by the basin of Red River; on the south by Minnesota River drainage area. (See Pl. II.)

SOURCE, COURSE, AND SLOPE OF THE RIVER.

The determination of the primal source of Mississippi River has been the cause of much controversy among explorers and geographers, by whom one or another of various small lakes has been considered the body of water in the Mississippi system that lies most remote from the Gulf of Mexico and stands at the highest elevation above it. For the purposes of the present report it is sufficient to state that the headwaters of the Mississippi lie within Itasca State Park, a tract of reserved land in Clearwater County, a detailed survey of which was made by the Mississippi River Commission.[b] Lake Itasca, which is the largest body of water within this park and which may be regarded as the source of the river, is in its north-central portion. The lake is long and narrow and is divided at its upper or southern end into an east and a west fork, each of which is connected by small creeks with other bodies of water. It is about 7 miles long and one-half mile wide and has an average depth of 20 feet. Its shores are generally swampy; indeed, a great part of the Itasca reservation is wooded swamp land, in some parts of which it is difficult to determine the direction of the water flow.

[a] Ann. Rept. Chief of Engineers, U. S. Army, for 1882, p. 1750; also for 1881, p. 1679.
[b] Map of Lake Itasca Basin, Minnesota, within Itasca State Park, Mississippi River Commission, 1900.

The river is 10 to 20 feet wide where it issues from Lake Itasca, at the northern boundary of the park, whence it meanders through a narrow, marshy valley northeastward to Lake Irvine, 1 mile above which it is joined by Schoolcraft River, a small stream draining Lakes George and Plantagenet. Lake Irvine, which is nearly circular in outline, has an average diameter of 1 mile and a general depth of 20 feet. After leaving Lake Irvine the river traverses a narrow neck of land to Lake Bemidji, which is approximately 5½ miles long and 2½ miles wide at its widest part. There is a perceptible current across the lake in a channel having a depth of 50 feet. The river is 60 feet wide and 1 to 3 feet deep at the lake outlet, and falls over intermittent rapids by a tortuous course to Cass Lake, a body of water that measures 9 miles from the point of entrance of the river to its place of exit at the northeast corner. A marshy tract, which at ordinary stages has no definite current through it, connects this lake at its southern extremity with Pike Bay, an oval lake having a circumference of 2 miles. From Cass Lake the river flows in a tortuous course about 8 miles eastward to Lake Winnibigoshish, a rectangular body of water about 6 miles wide and 12 miles long. A dam is maintained at the outlet of this lake. From the northeast corner of Lake Winnibigoshish the river flows generally southeastward as a sluggish, meandering stream, through bogs and marshes, to Pokegama Falls, where a concrete dam has been constructed. Four miles below this point, at Grand Rapids, there is another fall.

Between Lake Winnibigoshish and Pokegama Falls, Vermilion River and Leech Lake River enter the Mississippi from the south. Leech Lake River is the outlet of Leech Lake, a large, irregular-shaped body lying south of Cass Lake in Cass County.

From Grand Rapids to Aitkin, a distance of 130 miles, the Mississippi is navigable for light-draft steamers, which make regular trips during the open season. Swan, Sandy Lake, and Mud rivers enter the Mississippi from the east above Aitkin. Between Aitkin and Brainerd there are several falls, the principal of which are Big Eddy, Island, and French Rapids. Pine River enters from the west between these two cities. Ten miles below Brainerd Crow Wing River enters from the west. From Brainerd to Little Falls the stream consists of short stretches of rapids with intervening reaches of still water. At Little Falls there is a developed head of 12 feet. The bed of the river from Little Falls to Minneapolis is steep and the current rapid as compared with the other parts. The average slope in this stretch is 2.6 feet per mile. (See fig. 1.) The descent is, however, by no means even or regular. From Little Falls to St. Cloud there are several series of rapids, and at St. Cloud there is a fall of 14.5 feet. Sauk River enters from the west just above St. Cloud. Rapids and still-water stretches occur alternately between St. Cloud and Anoka, where

Alexandria
POPE
AREA
DRAINAGE
RIVER
MINNESOTA
KA
SCALE OF MILES
10
0
10

Rum River, the outlet of Millelacs, enters. Crow River, an important stream draining much of the southern part of the upper Mississippi area, enters a few miles above Anoka. Below Anoka the descent of the Mississippi is rapid. At Minneapolis the river falls 77 feet in 4 miles, and in this stretch it enters the deep, wide valley of its lower course.

From Lake Itasca to Minnesota River, a distance of 540 miles, Mississippi River has a total fall of 776 feet, which is an average slope of 1.4 feet per mile. (See fig. 1.)

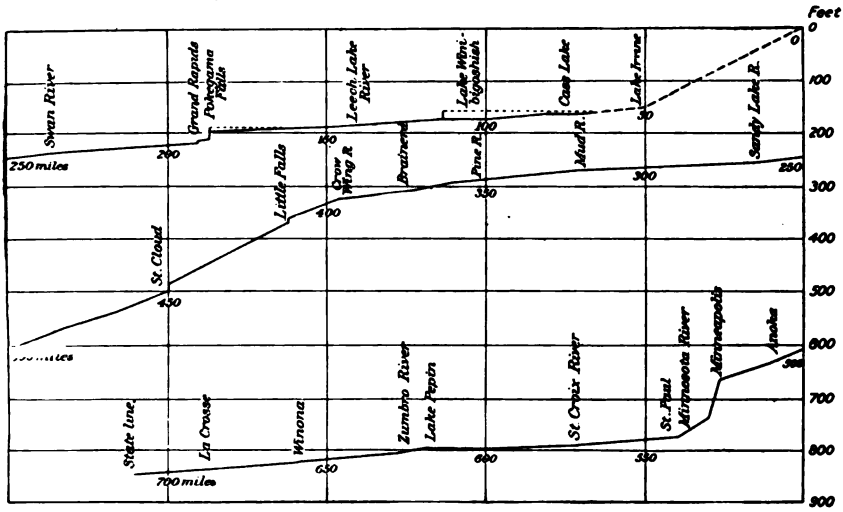

FIG. 1.—Profile of Mississippi River.

STORAGE RESERVOIRS.

The construction of dams in upper Mississippi Valley for the purpose of retaining flood waters was begun by the War Department in 1880. The original project [a] was to construct forty-one reservoirs in Minnesota and Wisconsin for the purpose of collecting surplus water to be released for the benefit of navigation during periods of low water. Between 1880 and 1895 five rock-filled timber-crib dams with earth embankments were built. In 1898 the replacement of these wooden dams by permanent concrete structures was commenced. After this part of the work has been completed probably no further reservoirs will be undertaken. Those now in operation are as follows:

1. Winnibigoshish dam, at foot of Lake Winnibigoshish.
2. Leech Lake dam, at foot of Leech Lake.
3. Pokegama dam, at Pokegama Falls, 4 miles above Grand Rapids.
4. Pine River dam, at foot of Cross Lake.
5. Sandy Lake dam, between Sandy Lake and Mississippi River.

[a] Ann. Rept. Chief of Engineers, U. S. Army, for 1904, pt. 1, p. 422.

TABLE 15.—*Storage reservoirs in upper Mississippi Valley.*[a]

Reservoir.	Area of watershed.	Area of reservoir surface.		Height of dam.	Reservoir capacity.[b]
		High water.	Low water.		
	Sq. miles.	*Sq. miles.*	*Sq. miles.*	*Feet.*	*Cubic feet.*
Winnibigoshish	1,442.43	161.26	117.00	14	45,000,000,000
Leech Lake	1,162.80	233.80	173.19	6	30,000,000,000
Pokegama	660.23	45.29	24.13	9	4,700,000,000
Pine River	562.07	23.76	18.30	17	7,500,000,000
Sandy Lake	421.50	16.52	8.00	7	3,158,000,000
					90,358,000,000

[a] Ann. Rept. Chief of Engineers for 1894, pt. 3, p. 1704.
[b] Ann. Rept. Chief of Engineers for 1900, p. 2798.

The total storage given above would be sufficient to supply the river with 11,000 second-feet for ninety days, though it is of course impossible to discharge the water at that rate, and the reservoirs are not filled to their maximum capacity. Records giving the dates for releasing the water and its effect at St. Paul[a] show that a release at Pokegama Falls is followed by a rise at St. Paul in seven or eight days, and that the full effect appears in twelve days, making the mean time ten days. The rise is about 1 foot at St. Paul. This would indicate that it takes eight days for water to travel from Pokegama Falls to St. Paul, a distance of 350 miles.

TRIBUTARIES OF MISSISSIPPI RIVER.

The drainage areas of the principal tributaries of Mississippi River above Minnesota River are given in the following table:

TABLE 16.—*Principal tributaries of Mississippi River above Minnesota River.*[b]

[Drainage area in square miles.]

Leech Lake	1,001
Pine	788
Crow Wing	3,562
Sauk	981
Crow	2,961
Rum	1,542

GEOLOGY.

The greater part of upper Mississippi Valley is underlain by Archean and Algonkian rocks, a few scattered outcrops of which appear in the beds of streams. Along the western border and in the northern third of the area alkaline formations of Cretaceous age overlie the early rocks. Cambrian and Ordovician limestones, sandstones, and dolomites occur in a comparatively small section of the southern part of the area. Drift covers the entire area to depths

[a] Ann. Repts. Chief of Engineers for 1895 and 1896.
[b] Ann. Rept. Chief of Engineers, U. S. Army, for 1875, pt. 2, p. 437.

ranging from 50 to 200 feet and furnishes the supply of water for most of the wells. The river channels above Minneapolis are excavated in drift. Below Minneapolis the Mississippi runs through a deep, wide gorge cut in sedimentary rocks, a gorge formed above Fort Snelling, probably, by the recession of St. Anthony Falls.[a]

SOIL AND SUBSOIL.

The upper layers of the drift here contain less soluble mineral matter than is contained in the drift of the prairie regions. This difference may be due both to difference in climate and to difference in the character of the underlying formations. From published analyses in bulletins of the agricultural experiment station, University of Minnesota, averages have been computed for samples of soil taken from points in all parts of the upper Mississippi area. The average composition of soils taken throughout the entire State is given for comparison.

TABLE 17.—*Chemical composition of soil and subsoil in upper Mississippi basin.*

	Surface soil.		Subsoil.	
	Upper Mississippi River basin.	Entire State.[a]	Upper Mississippi River basin.	Entire State.[a]
Insoluble in HCl	86.92	79.92	87.27	82.41
Volatile matter	5.88	8.98	3.33	5.33
Potassium oxide (K_2O)	.23	.43	.24	.40
Sodium oxide (Na_2O)	.29	.45	.25	.32
Calcium oxide (CaO)	.68	1.29	.92	1.78
Magnesium oxide (MgO)	.40	.61	.38	.86
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	4.88	7.20	5.85	8.32
Phosphoric anhydride (P_2O_5)	.19	.20	.17	.17
Sulphuric anhydride (SO_3)	.07	.10	.05	.06
Carbonic anhydride (CO_2)	.08	.62	.30	.93

[a] Snyder, H., Characteristic features of Minnesota soils and conservation of fertility: Bull. Chem. Div., Agric. Exp. Sta., University of Minnesota, No. 65, Nov., 1899, p. 69.

From Table 17 it is seen that all the alkaline and alkaline-earth ingredients of the soils of the upper Mississippi region are lower than the average in the soils throughout the State, and it appears, therefore, that the ground is less easily disintegrated and carried off in solution by the surface drainage. It will be noted, however, that there is enough calcium and magnesium to cause the hardness always observed in the water of Mississippi River. The soils in general contain sand, and the particles are larger than those in Red River Valley or in the southern part of the State. They are of much the same chemical composition as those in the valley of St. Croix River, though they usually contain more alkaline-earth compounds and more organic or volatile matter.

[a] Winchell, N. H., Geology of Hennepin County, Final Rept. Minnesota Geol. and Nat. Hist. Survey, vol. 2, p. 315.

INDUSTRIAL POLLUTION.

KINDS OF POLLUTION.

From reports received in June, 1905, the following list has been compiled to show the number of establishments likely to furnish deleterious or undesirable wastes to streams in this region.

TABLE 18.—*Industrial establishments causing stream pollution in upper Mississippi River basin.*

Breweries	18
Dye works	6
Gas works	1
Paper mills	5
Sawmills	36
Starch factories	4
Sugar factories	1
Tanneries	3
Woolen mills	3

LUMBERING.

Lumbering and its attendant industries are the sources of a great amount of the organic matter in the surface waters of this section. Almost the entire area was formerly covered by pine forest. At present nearly all the standing timber is north of Brainerd, comprising an area extending eastward from the headwaters of the Mississippi. The supply of lumber is rapidly diminishing, so that in a few years this enormous industry will no longer be first in rank. Table 19 shows the total number of feet of logs sawed in the second lumber district of Minnesota from 1891 to 1904. Though the figures include a small amount sawed at Red Wing and at Hastings on the lower river, they practically represent the sawmill industry of the region under consideration.

TABLE 19.—*Lumber sawed in second district of Minnesota, 1891–1904.*[a]

Year.	Feet B. M.	Year.	Feet B. M.
1891	425,765,260	1898	533,179,510
1892	505,407,898	1899	678,364,430
1893	428,172,360	1900	604,328,300
1894	459,862,756	1901	690,147,940
1895	539,012,678	1902	576,555,305
1896	385,312,226	1903	590,965,050
1897	527,367,710	1904	557,717,210

The total cut in the same region during the winter of 1903–4 was 674,981,820 feet B. M.; during the winter of 1904–5 it was 536,701,660 feet B. M. The amounts sawed at certain points during the calendar years 1903 and 1904 are shown on the page following.

TABLE 20.—*Lumber sawed in second district of Minnesota, 1903–4.*[a]

Place.	Feet B. M.		Number of employees in 1904.[b]
	1903.	1904.	
Akely	52,000,000	52,000,000	393
Bemidji	34,500,000	30,540,000	430
Brainerd	29,000,000	29,000,000	467
Cass Lake	15,500,000	20,000,000	136
Cohasset	1,200,000	1,200,000	.....
Hastings[c]	6,000,000	4,000,000	75
Little Falls	57,366,620	60,284,440	361
Milaca	29,627,500	31,000,000	291
Minneapolis	328,434,590	293,574,590	2,887
Park Rapids	12,100,000	13,500,000	101
Red Wing[a]	6,500,000	7,500,000	100
Sauk Rapids	7,486,340	8,296,480	62
Ten Strike	.....	533,000	.....
Turtle River	3,250,000	2,288,700	.....
Mills not included in above	8,000,000	4,000,000	.....
	590,965,050	557,717,210	.....

[a] Letter from surveyor-general of logs and lumber, second district of Minnesota.
[b] Ann. Rept. Comm. of Labor of Minnesota, 1903–4.
[c] On Mississippi River below St. Paul.

The preceding statistics show the magnitude of the lumber industry in this region. As noted on page 34, the three probable sources of pollution of streams by this industry are the logs, the sawdust or other waste, and the employees. Although the mills are provided with huge stacks in which great quantities of the waste are burned for steaming, much sawdust and bark reach the streams, especially during floods. This material deposits at certain places so as to obstruct the flow of the river; later it decays and gives the water a vegetable or a moldy odor.

The logs are kept in the water from the time they are first floated until they are sawed. It is probable that extract from the logs during this long-continued soaking forms an appreciable part of the vegetable matter in the water. It is worthy of note that the most highly colored surface waters are found in those areas in which lumbering is most extensively practiced.

The men who handle the logs, the "lumber jacks," practically inhabit the streams and are constantly in them. They commonly micturate and defecate in the streams or in places near them, whence their bodily excretions are directly transferred to the water. At Minneapolis, where several hundred men are employed in this manner, just above the principal water intake, efforts have been made by the city health commission to reduce this dangerous pollution by establishing closets on the banks of the river.[a]

[a] Rinker, Cappelen, Hazen, Report of commission appointed by the city council of the city of Minneapolis to investigate and report the best method of filtration of water from the Mississippi River, 1904, p. 5.

PAPER MILLS.

Five mills were reported on upper Mississippi River. At Grand Rapids is a ground-wood pulp mill, owned by the Itasca Paper Company, generally employing 120 persons. No chemicals are used, except very small quantities of alum and soda ash. When the mill is in full operation, between 500 and 800 gallons per minute of waste water, cloudy in appearance, is discharged into Mississippi River. A ground-wood pulp mill, owned by the Northwestern Paper Company, is located one-half mile above the intake of the city waterworks at Brainerd. The average number of employees is 33. No chemicals are used. The effluent from the grinders and the felting machine is discharged directly into Mississippi River. The average daily output is 30 tons of wet pulp. At Little Falls there is a ground-wood paper mill owned by the Hennepin Paper Company. The average number of employees is 60. No chemicals are used. Waste is discharged into Mississippi River. The average daily output is 20 tons of printing paper, or 25 tons of manila wrapping paper. Two miles above Sauk Rapids on Mississippi River the Watab Pulp and Paper Company has recently erected a plant for the manufacture of news paper. It is a ground-wood mill, using no chemicals except small amounts of alum and clay. All waste water is passed through a 70-mesh screen before being discharged into the river. The capacity of the mill is 35 tons daily. At Minneapolis there is a ground-wood paper mill owned by the Nelson Paper Company. The average number of employees is 50. The effluent is discharged into Mississippi River. The daily capacity is 20 tons of carpet lining, felt, and rosin-sized sheeting.

These establishments use the ground-wood process with no chemical treatment of the wood or the pulp except the addition of small amounts of sizing and filler. The effluent is a thin liquid, milky or watery in appearance, containing fine particles of pulp and grindstone in suspension, besides resins and juices dissolved from the wood. The larger particles of pulp are always screened out as a matter of economy, but a small amount escapes with the effluent. The material is generally considered an innocuous but undesirable addition to the water. It probably has the same effect as the waste from sawmills.

SUGAR INDUSTRY.

The only beet-sugar factory in the State was built at St. Louis Park on Minnehaha Creek, a small stream entering Mississippi River just below Minneapolis. In 1902 complaint was made that the factory polluted the creek,[a] making it unfit for cattle to drink and killing the fish in it.

[a] Biennial Rept. Minn. State board of health. 1901-2, pp. 267-269, 416.

Examination showed two different effluents—one, containing possibly some contamination, is spread over sandy soil, where it is absorbed; the other is the water used for washing the beets, and it is discharged into settling tanks, whence it passes into the creek over brush and stone so placed as to collect any floating débris. The beet pulp is sold for stock food. The waste molasses, which was at first allowed to flow into the stream, was later preserved and sold. It was the opinion of those who conducted the inspection that no serious pollution emanated from the sugar factory. Analysis of samples above and below the plant failed to reveal any appreciable increase of organic matter.

TABLE 21.—*Analyses of waters at plant of Minnesota Sugar Company.*

[Parts per million. H. C. Carel, analyst.]

Source.	Chlorine.	Nitrates.	Nitrites.	Ammonia.		Oxygen consumed.
				Free.	Albuminoid.	
Minnehaha Creek above drain of Minnesota Sugar Co	0.9	0.0	0.0	0.10	0.26	8.6
Minnehaha Creek 100 feet above drain	.8	0.0	(a)	.03	.26	.....
Minnehaha Creek 100 feet below drain	.9	0.0	0.0	.09	.27	9.4
Minnehaha Creek at bridge of Electric R. R. Co	.9	0.0	0.0	.10	.26	9.2
Minnehaha Creek 300 yards below drain	.8	0.0	(a)	.05	.29	.....
Drain of Minnesota Sugar Co	.9	0.0	0.0	.10	.27	9.8

[a] Slight trace.

OTHER INDUSTRIES.

With the exception of those at Minneapolis, the breweries are small. Their waste, consisting of barrel and vat washings and a milky water left after screening out the "grains," is commonly run into adjacent brooks and ponds, where it putrefies and causes a more or less disagreeable odor and appearance, varying with the degree of dilution. Creamery waste is principally sour wash water. Offal from small slaughterhouses is sometimes thrown into the streams, though this is contrary to regulations, which provide for the deep burial of all matter that is not preserved in the slaughterhouse. In the larger packing houses a bloody, greasy liquid, of foul odor, containing much readily putrescible matter, flows away from the skimming tanks. Starch factories discharge effluents containing vegetable matter in greater or less amount, the quantity depending on the economy of the processes employed. Tannery wastes contain lime, hide soakings, hair, and spent liquors. The wastes from all these industries are probably not inherently toxic in the quantities which are present. They are undesirable and objectionable in that they contain organic matter capable of causing nuisances by putrefaction and of becoming foci for the develop-

ment of pathogenic organisms. In most cases the effluents contai valuable ingredients for which research has found or will find som economical method of recovery.

MUNICIPAL POLLUTION.

PROBABILITY OF POLLUTION.

In the discussion of probable pollution from centers of populatio it should be remarked that there is always drainage of some sort fro every collection of people, whether it consists of one family or te thousand, and whether it is connected with an adjacent stream b sewers or by surface washing. The dejecta of one infected househol has caused typhoid epidemics as disastrous as those originating fro a sewered city, though the probability of infection is less. Therefo the surface water from an inhabited area is always liable to infectio The prospect of pollution is uncertain and depends upon many facto other than the population per square mile. Climate, geology, th chemical quality of the water, rate of stream flow, dilution, th virility of the organisms, as well as their food supply, and man other conditions influence the distance which the pathogenic bacteri may be borne by water. Recent investigators with cultures of *B. typhosus* in permeable sacs found the organism able to retain its vitality from six to ten days in the water of Lake Mendota, Wis., four to eight days in Lake Michigan water, three to five days in raw sewage, and one to three days in Chicago River. Other bacteriologists have found longer periods of survival.[a] In view of the fact, therefore, that the life period of *B. typhosus* in water is variable and at present not determinable with any degree of safety, it is well to assume that no surface water coming from an inhabited area should be used as a municipal supply without artificial purification. Cities that use raw stream water as a public supply are always in danger of typhoid epidemics and generally have higher typhoid rates than those that procure their domestic supplies in some other manner.

POPULATION.

Application of the general principle stated above to upper Mississippi River demonstrates that its waters are not suitable for municipal use without filtration. Table 22 shows the distribution of population by counties in the drainage area for the years 1890, 1900, and 1905. Table 23 shows the density of population in the region. The method used in dividing the total population of a county between two or more

[a] See Eng. Record, Dec. 24, 1904; Sept. 23, 1905; Jour. Infectious Diseases, vol. 1, No. 4; Testimony, State of Missouri v. Sanitary District of Chicago, p. 2600 et seq.

drainage areas was as follows: The population of villages and cities exceeding 1,000 was subtracted from the total population of the county, and the remainder was divided according to the areas of the county sections in each drainage basin; the population of each settlement was then added to that of the basin in which the settlement is located.

TABLE 22.—*Population in upper Mississippi River basin.*

County.	U. S. census of 1890.	U. S. census of 1900.	State census of 1905.
Aitkin	2,262	6,355	8,851
Anoka	9,884	10,939	11,673
Becker	2,630	3,772	5,063
Beltrami	212	5,132	[a] 7,304
Benton	6,284	9,912	11,256
Carlton	548	1,389	1,609
Cass	1,247	7,777	11,012
Carver	4,774	5,126	5,209
Clearwater	.....	.....	[a] 1,409
Crow Wing	8,852	14,250	16,731
Douglas	8,598	10,730	11,398
Hennepin	183,566	226,428	290,719
Hubbard	1,412	6,578	9,008
Isanti	7,372	11,303	12,489
Itasca	543	2,934	6,749
Kandiyohi	6,086	7,502	7,787
McLeod	14,594	16,795	16,556
Meeker	15,456	17,753	17,953
Mille Lacs	2,645	7,766	9,476
Morrison	13,325	22,891	24,584
Ottertail	9,693	12,358	13,025
Pope	1,881	2,289	2,329
Ramsey	3,320	3,745	4,654
Renville	4,106	5,412	5,696
Sherburne	5,908	7,281	7,961
Stearns	34,844	44,464	47,120
Todd	12,030	22,214	24,638
Wadena	4,053	7,921	9,317
Wright	24,163	29,157	29,467
Chippewa Reservation	([b])	([b])	1,920
	391,188	530,173	632,963

[a] Clearwater County organized from part of Beltrami County since 1900.
[b] Included under county populations in U. S. censuses.

TABLE 23.—*Density of population in upper Mississippi River basin.*

	Drainage area.	Inhabitants per square mile.		
		1890.	1900.	1905.
Above Grand Rapids:	*Square miles.*			
Entire area	[a] 3,665	0.6	3.9	6.3
Excluding chief settlements		.6	3.0	4.7
Above St. Cloud:				
Entire area	[a] 13,872	7.6	12.5	14.7
Excluding chief settlements		6.4	10.1	11.8
Above Minneapolis:				
Entire area	[b] 19,585	11.2	16.6	18.2
Excluding chief settlements		9.3	14.0	15.0
Above Minnesota River:				
Entire area	[c] 19,731	19.8	26.9	32.1
Excluding chief settlements		9.4	14.2	15.4

[a] Ann. Rept. Chief of Engineers, U. S. Army, 1875, pt. 2, p. 437.
[b] U. S. Water Power Census, vol. 2, 1880, p. 138.
[c] Ann. Rept. Chief of Engineers, U. S. Army, 1894, pt. 3, p. 1704.

The present density of population for the entire area is considerably higher than that for the State (25 per square mile). Excluding Minneapolis, the population of which is over one-third of the total, the density is about 20 persons per square mile. This is not high as compared with some parts of the United States. Since, however, nearly 50 per cent of the inhabitants are concentrated in cities and villages that stand on the banks of the principal streams and are sewered directly into them, there is abundant opportunity for water pollution. It should be noted that the population is rapidly increasing, so that the pollution is likely to be much greater.

CONDITIONS ON THE MISSISSIPPI.

General conditions.—Pl. II shows the hydrography of the region and the location of all settlements exceeding 1,000 population according to the census of 1900. Those which have established sewerage systems are indicated by a vertical bar within the population circle. The most noticeable features are as follows: (1) All the settlements except one are in direct stream connection with Mississippi River, since they are situated on the banks of either the main stream or one of its tributaries; (2) the majority of urban centers are in the southern half of the area; (3) the four larger cities, aggregating 285,385 inhabitants, or 45 per cent of the total population in the basin, are on the main stream and are connected directly with it by sewerage systems discharging sewage without purification.

Conditions at Grand Rapids.—The portion of the basin above Grand Rapids is one of the least populated areas in the State, and it may still be called an undeveloped region. Bemidji, on Lake Bemidji; Walker, on Leech Lake; and Cass Lake, on Cass Lake, are all small villages. Much of this area is included in Indian reservations and comprises considerable timber and swamp land. Three of the largest lakes in the State are situated in this section.

Conditions at St. Cloud.—The portion of the basin above St. Cloud, which includes about 70 per cent of the upper Mississippi basin, is principally deforested land now cultivated. The chief sources of river pollution above St. Cloud are given in Table 24.

TABLE 24.—*Principal settlements above St. Cloud.*

Name.	Stream.	Distance above St. Cloud. [a]	Population.		
			1890.	1900.	1905.
Aitkin	Mississippi River	130	737	1,719	1,896
Alexandria	Lake Agnes	160	2,118	2,681	3,051
Bemidji	Lake Bemidji	400	.....	2,183	3,800
Brainerd	Mississippi River	75	5,703	7,524	8,133
Grand Rapids	Mississippi River	260	.....	1,428	2,055
Little Falls	Mississippi River	38	2,354	5,774	5,856
Long Prairie	Long Prairie River	120	1,206	1,385	1,256
Melrose	Sauk River	50	780	1,768	2,151
Park Rapids	Fishhook River	140	.....	1,313	1,719
Sauk Center	Sauk River	70	1,695	2,220	2,463
Sauk Rapids	Mississippi River	2	1,185	1,391	1,552
Staples	Crow Wing River	94	842	1,504	2,163
Wadena	Union Creek	110	895	1,520	1,868
Total urban population			17,515	32,410	37,963

[a] St. Cloud is 76 miles above Minneapolis.

Conditions at Minneapolis.—The pollution above Minneapolis has been discussed by the Minneapolis water commission, which recommended that Mississippi River at this point should be purified by slow sand filtration.[a] The length of time for the passage of water from Grand Rapids to St. Paul at low-water stage has been calculated by the U. S. Engineering Corps as eight days. From the slope of the river (fig. 1) and the fact that the typhoid bacillus has lived for three to ten days in water similar to that of Mississippi River, it may be considered probable that Minneapolis is not exempt from infection by several cities on its watershed. In addition to the urban pollution there are farmhouses and other isolated dwellings scattered along the river, infection from which might reach the city. The principal settlements on the stream, with the distance above Minneapolis, and their population, are given in the following table. Comparison of the populations for successive censuses shows that nearly all of these places are growing rapidly.

TABLE 25.—*Principal settlements above Minneapolis.*

Name.	Stream.	Distance above Minneapolis.	Population.		
			1890.	1900.	1905.
		Miles.			
Settlements above St. Cloud (See Table 24, above.)		.....	17,515	32,410	37,963
Anoka	Rum River	17	4,252	3,769	4,053
Buffalo	Buffalo Lake	60	606	1,040	1,124
Glencoe	Buffalo Creek	85	1,649	1,780	1,805
Hutchinson	South Fork Crow River [b]	100	1,414	2,495	2,489
Litchfield	Jewett Creek	105	1,899	2,280	2,415
Milaca	Rum River	95	404	1,204	1,319
Princeton	Rum River	80	816	1,319	1,704
St. Cloud	Mississippi River	76	7,686	8,663	9,422
White Bear Lake	White Bear Lake	40	1,356	1,288	1,724
Total urban population			37,597	56,248	64,018

[a] Rinker, Cappelen, and Hazen, op. cit. [b] Locally known as Hassan River.

TYPHOID FEVER.

The relations between the principal settlements and the streams, as shown in Pl. II, counterbalance to some extent the comparatively low population per square mile and explain the prevalence of typhoid fever. Aitkin takes its domestic supply from Mud River. Brainerd, below Aitkin, uses Mississippi River water, as do also Little Falls, St. Cloud, and Minneapolis, all without filtration. Each in turn discharges sewage directly into Mississippi River without purification. In this manner each is exposed to infection from its neighbors above and subjects its neighbors below to additional danger. Epidemics of typhoid fever have visited nearly every community in the area, and the disease is always prevalent. Records at Minneapolis are as follows:

TABLE 26.—*Typhoid fever at Minneapolis.*[a]

Year.	Typhoid cases.	Typhoid deaths.	Typhoid death rate per 100,000.[b]	Ratio of deaths to cases (percent).
1891	583	93	54.7	16
1892	462	76	44.7	16
1893	1,080	134	74.4	12
1894	847	101	56.2	12
1895	740	88	48.8	12
1896	435	60	31.6	13
1897	1,534	148	77.9	9
1898	689	86	43	12
1899	537	71	35.5	13
1900	376	79	39.5	21
1901	630	121	57.6	19
1902	320	66	28.7	21
1903	720	95	39.5	13
1904	738	103	41.2	14
Averages			48.1	14

[a] Hall, Dr. P. M., Ann. Rept. Dept. of Health, Minneapolis, 1904, p. 19.
[b] Population computed from the average annual increase shown by the censuses of 1890, 1900, and 1905.

The relationship of water supply and typhoid fever at Minneapolis has been extensively investigated, and reports of the findings have been published.[a] The severest epidemic in late years occurred in 1897, when 1,534 cases were reported, a record closely approached in 1893, when there were 1,080 cases. In the first three months of 1904 there were over 450 cases, with 61 deaths. A study of the progress of the disease for several years has shown that the severest epidemics occur after the introduction of water from the two lower pumping stations,[b] while the least typhoid is reported when the supply is drawn exclusively from stations at the northern limits of

[a] Rinker, Cappelen, Hazen, Rept. of Minneapolis Water Commission, 1904; Hall, Dr. P. M., Ann. Repts Dept. of Health of Minneapolis; Corbett, Dr. J. F., Typhoid and water supply: Ann. Rept. Minneapolis Dept. of Health, 1904, p. 27; Smith, E. G., The Mississippi River as the Source of Water Supply for the Inhabitants of the Mississippi Valley: Jour. New Eng. Waterworks Assoc., 1905, vol. 19, p. 217; Bass, F. H., An epidemic of typhoid fever in East Minneapolis: Eng. News, March 3, 1904, vol. 51, p. 205.
[b] See p. 63 for location of intakes.

the city. Continued bacteriological examinations of the water for more than 100 miles above the city have demonstrated the pollution of the river water.

At St. Cloud well-marked epidemics have occurred and the disease has seldom been absent. In twenty-one months from November 1, 1900 to August 1, 1902, 154 cases were reported, with 12 deaths. In 1901 a general spread of the disease over the city was attributed to infection of the water supply by seepage from the sewer of a hosiptal at which typhoid patients were being treated. The supply, which is taken from Mississippi River without filtration, has been repeatedly condemned by the State board of health.

The records of deaths from typhoid fever indicate that the disease is not confined to the cities, but is prevalent as well in the rural districts.

QUALITY OF WATER.

Samples of water were taken at points in the basin[a] above and below the principal settlements, and examined for the purpose of ascertaining the general characteristics of the stream water and the changes that might occur in it from place to place. Since it was not possible, on account of the expense, to make weekly or even monthly examinations of water from all stations, the samples were collected in series under conditions as nearly similar as practicable. Series I of Table 27 was taken during the late fall and early winter of 1903; Series II was collected during the early part of 1904, at a time when the waters had been icebound for more than two months; Series III, taken during May and June, 1904, represents the water during the decline following the spring floods. During the period intervening between the first and the last samples the river fluctuated comparatively little; gage readings at the Survey station above Sauk Rapids show a total fall of 1.65 feet between May 18 and June 18. Between September 2 and November 4, when Series IV was taken, there was some change in the stream discharge. Heavy rains in October caused a gradual rise of the river, which reached its maximum about the middle of the month and then declined, so that the samples taken at Anoka probably represent a greater dilution than those taken at St. Cloud. Series V was collected during the latter part of the winter in 1905. The river was frozen during this period and there was little change in the discharge.

[a] See Pl. I for location of sampling stations.

TABLE 27.—*Quality of water in Mississippi River basin above Minnesota River.*

[Parts per million.]

SERIES I. FALL AND WINTER OF 1903.

Source.	Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Total alkalinity.	Total hardness.	Iron as Fe.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Free CO_2.	Bacteria per c.c.[a]	B. coli communis.[a]
Mississippi River:																		
Entrance into Lake Bemidji[b]	Dec. 15	13	0	<7	0.2	0	182	189	.....	.....	.....	0.21	0.065	0.000	0.00	.....	120	−
At Cass Lake[b]	Dec. 14	4	0	<7	.2	0	153	158	.....	.....	.....	.24	.125	.000	Trace.	.....	450	−
Above Grand Rapids[c]	Dec. 12	22	.....	<7	.....	0	142	140	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Above Brainerd[d]	Oct. 26	.....	.....	.....	1.0	.....	.....	83	.....	.....	.....	.28	.04	.000	Trace.	.....	75	+
Waterworks, Brainerd[d]	do	.....	.....	.....	1.0	.....	.....	84	.....	.....	.....	.24	.06	.000	Distinct.	.....	31	+
Above large sewer, Brainerd[d]	do	.....	.....	.....	1.0	.....	.....	80	.....	.....	.....	.30	.04	.000	Trace.	.....	95	+
Below large sewer, Brainerd[d]	do	.....	.....	.....	1.6	.....	.....	80	.....	.....	.....	.32	.04	Trace.	Distinct.	.....	2,200	+
Above Sauk Rapids[d]	do	.....	.....	.....	1.2	.....	.....	116	.....	.....	.....	.26	.04	.000	Trace.	.....	70	+
Waterworks, St. Cloud[d]	do	.....	.....	.....	1.0	.....	.....	122	.....	.....	.....	.24	.03	.000	Distinct.	.....	170	+
Below St. Cloud[d]	do	.....	.....	.....	1.6	.....	.....	116	.....	.....	.....	.09	.01	.000	Distinct.	.....	375	+
Tributaries:																		
Hale Lake at Grand Rapids[c]	Dec. 12	40	3 e.	8	.....	0	100	103	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

SERIES II. WINTER OF 1904.

Source.	Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Total alkalinity.	Total hardness.	Iron as Fe.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Free CO_2.	Bacteria per c.c.[a]	B. coli communis.[a]
Mississippi River:																		
Above Schoolcraft River[b]	Jan. 28	25	4 v.	<7	0.3	0	268	178	.....	.....	.....	0.16	0.191	0.000	Trace.	.....	425	−
Entrance into Lake Bemidji[b]	do	4	0	<7	.3	0	205	130	.....	.....	.....	.21	.141	Trace.	0.00	.....	60	−
Below Lake Bemidji[b]	do	25	2 v.+2 m.	<7	.3	0	232	171	.....	.....	.....	.23	.071	Trace.	Trace.	.....	250	−
Below Cass Lake[b]	Jan. 29	18	0	<7	.3	0	162	110	.....	.....	.....	.80	.275	.000	Trace.	.....	47	−
Above Grand Rapids[b]	Jan. 30	40	2 e.	<7	.3	0	164	158	.....	.....	.....	.95	.55	Trace.	Trace.	.....	.....	−
Above Mud River[b]	Feb. 8	74	2 v.	<7	.....	0	139	99	.....	.....	.....	.....	.....	.....	.....	.....	140	−
Below Mud River[b]	do	81	2 v.	10	.2	0	143	166	.....	.....	.....	.30	.12	.000	Trace.	.....	300	−
Above Brainerd[b]	Feb. 10	60	.....	10	.3	0	131	154	.....	.....	.....	.31	.17	Trace.	Distinct.	.....	110	+
Waterworks, Brainerd[b]	do	56	.....	16	.3	0	131	166	.....	.....	.....	.30	.13	Trace.	Distinct.	.....	160	+
Below Brainerd[b]	do	60	.....	15	.3	0	131	163	.....	.....	.....	.32	.16	Trace.	Distinct.	.....	1,700	+
Above Sauk Rapids[d]	Jan. 5	.....	.....	.....	.5	.....	.....	212	.....	.....	.....	.14	.22	.000	Distinct.	.....	.....	+
Waterworks, St. Cloud[d]	do	.....	.....	.....	.5	.....	.....	229	.....	.....	.....	.24	.28	.000	Distinct.	.....	225	+
Below St. Cloud[d]	do	.....	.....	.....	.8	.....	.....	229	.....	.....	.....	.25	.28	.000	Distinct.	.....	.....	+
Tributaries:																		
Mud River above Aitkin[b]	Feb. 8	65	2 v.	<7	.2	0	87	89	.....	.....	.....	.52	.23	Trace.	Distinct.	.....	350	−
[illegible]	do	[illegible]	[illegible]	[illegible]	.2	[illegible]	[illegible]	80	[illegible]	[illegible]	[illegible]	.43	.15	.000	Distinct.	[illegible]	500	−

Mississippi River:																	
Above Schoolcraft River [b]	May 18	60	3 v.	<7	0.3	0	143	141	0		0.23	0.05	0.000	Trace.			
Above Lake Bemidji [b]	do	56	3 v.	<7	.3	0	140	134	0		.30	.08	.000	Trace.			
Below Lake Bemidji [b]	do	25	2 v.	<7	.3	0	161	127	0		.18	.01	.000	Trace.			
Above Grand Rapids [b]	May 17	60	2 v.	10	.3	0	100	99	0		.26	.05	.000	0.00		650	−
Above Mud River [b]	May 22	116	3 v.+2 e.	20	.4	Trace.	64	74	0		.30	.07	.000	Trace.			+
Below Mud River [b]	do				.4			83			.35	.13	.000	Trace.		1,100	+
Above Brainerd [b]	May 21	121	2 M.	<7	.4	0	67	85	0		.44	.20	.000	Trace.		300	+
Waterworks, Brainerd [b]	do	121	2 M.	<7	.4	0	64	85	0		.29	.05	.000	Trace.		1,000	+
Below Brainerd [b]	do	121	2 M.	<7	.4	0	64	85	0		.41	.19	.000	Trace.		2,000	+
Above Sauk Rapids [d]	June 17				.2			110			.20	.05	.000	Trace.		1,300	+
Above St. Cloud [d]	do				1.5						.13	.07	.000	Marked.			
Waterworks, St. Cloud [d]	do				2.0						.22	.07	.000	Marked.		500	+
Above Rum River [e]	June 18	76			2.5					128	.212	.02	.000	.00		700	+
Below Rum River [e]	do	76			2.0					129	.222	.21	.000	.00		750	+
Below Minneapolis [d]	June 6				.2			130			.23	.10	.000	.00			
Tributaries:																	
Mud River above Aitkin [b]	May 22	74	3 v.+2 M	10	.4	0	64	70	0		.30	.10	Trace.	Trace.		2,800	+
Mud River 200 feet above intake, Aitkin [b]	do				.4						.42	.08	Trace.	Trace.		3,800	+
Mud River at intake, Aitkin [b]	do	74	3v.+2 M.	10	.4	0	66	87	0		.31	.23	Trace.	Trace.		1,400	+
Rum River above asylum, Anoka [e]	June 18	78			2.					153	.313	.046	.000	.03		650	+
Rum River below Anoka [e]	do	8			2.4					146	.332	.029	.000	.03		900	−
Hale Lake at Grand Rapids [b]	June 17	10	2 v.	<7	.4	0	120	113	0		.11	.01	.000	Trace.		130	−

[a] Bacteriological examinations by Dr. E. H. Beckman.
[b] Determinations of chlorine and nitrogen by H. C. Carel, other chemical determinations by R. B. Dole.
[c] Chemical analyses by R. B. Dole.
[d] Chemical analyses by H. C. Carel.
[e] Chemical analyses by G. B. Frankforter.

TABLE 27.—*Quality of water in Mississippi River basin above Minnesota River*—Continued.

[Parts per million.]

SERIES IV. FALL OF 1904.[a]

Source.	Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Total alkalinity.	Total hardness.	Iron as Fe.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Free CO_2.	Bacteria per c.c.[b]	B. coli communis.
Mississippi River:																		
Above Schoolcraft River	Nov. 2	40	0	<7	0.6	Trace.	226	208	Trace.	251	16	0.160	0.012	0.000	0.03	7	1,100	−
Below Lake Bemidji	...do...	18	0	<7	1.4	0	180	160	Trace.	198	19	.234	.030	.000	.03	1.1	300	−
Above Grand Rapids	Oct. 31	56	2 v.	<7	.9	0	141	132	Trace.	178	24	.282	.034	.000	.04	8	450	−
Above Mud River	Nov. 4	160	2 v.	17	1.2	0	97	96	Trace.	153	7	.368	.046	.000	.02	4	.....	+
Above Brainerd	Nov. 3	112	2 v.	13	1.1	0	96	104	1.5	147	17	.360	.030	.000	.02	6	275	+
Waterworks, Brainerd	...do...	112	2 v.	14	1.0	0	100	104	1.5	150	19	.382	.022	.000	.03	5	650	−
Below Brainerd	...do...	112	2 v.	15	1.0	0	100	104	1.5	142	14	.382	.040	.000	.03	6	850	+
Above Sauk Rapids	Sept. 4	56	0	15	.3	Trace.	137	132	Trace.	186	19	.270	.026	.000	.10	8	1,200	+
Waterworks, St. Cloud	...do...	60	2 v.+1 m.	20	.4	Trace.	156	159	Trace.	202	18	.318	.036	.000	.10	12	1,000	+
Below St. Cloud	...do...	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.300	.036	.....	.....	.....	1,100	+
Above Rum River	Oct. 20	56	2 v.+1 m.	55	.7	Trace.	130	132	Trace.	194	16	.418	.058	.000	.04	.....	2,600	...
Below Rum River	...do...	56	2 v.+1 m.	55	.8	Trace.	116	121	Trace.	192	25	.422	.052	.000	.04	.....	1,200	+
Tributaries:																		
Millelacs at Wealthwood	Nov. 4	18	0	<7	.2	Trace.	77	77	Trace.	112	7	.384	.012	.000	Trace.	6	95	−
Rum River at Anoka, above asylum	Oct. 20	88	2 v.	13	.9	0	76	76	0	138	13	.422	.054	.000	.00	.....	2,800	+
Rum River at Anoka waterworks	...do...	88	2 v.	13	1.1	0	74	77	0	136	15	.460	.054	.000	.00	.....	1,800	+
Rum River below Anoka	...do...	88	2 v.	20	1.0	0	73	77	0	125	10	.418	.060	.000	.00	.....	3,400	+
Lake Latoka, Alexandria	Sept. 2	4	0	<7	.5	Trace.	156	149	0	186	19	.280	.066	.000	.00	0	300	−
Lake Carlos, Alexandria	...do...	4	1 v.	<7	1.0	Trace.	170	204	0	198	22	.280	.014	.000	.00	0	70	−
Lake Osakis, Osakis	Sept. 3	18	2 v.	11	1.0	0	148	166	0	187	22	.368	.058	.000	.00	0	130	−
Sauk River above Sauk Center	...do...	25	3 v.	10	.3	5 est.	180	173	Trace.	205	23	.428	.112	.002	.02	8	700	−
Sauk River below Sauk Center	...do...	25	2 v +1 m.	10	.3	5 est.	181	173	Trace.	221	23	.462	.136	.003	.02	12	4,600	+
Sauk River above Melrose	...do...	.....	.....	.....	.4	5 est.	199	.....	.....	.....	.....	.....	.....	.....	.....	.....	900	+
Sauk River below Melrose	...do...	25	2 v.	<7	1.0	5 est.	201	215	0	234	18	.320	.076	.000	.02	10	1,700	+
Sauk River at mouth	Sept. 4	40	0	10	.4	Trace.	187	188	Trace.	235	23	.306	.048	.001	.09	14	1,500	+
Hale Lake at Grand Rapids	Oct. 31	18	2 m.	<7	.9	5 est.	147	132	Trace.	195	14	.148	.080	.000	.00	7	65	−
Leech Lake at Walker	Nov. 3	0	0	<7	1.2	5 est.	166	174	0	190	15	.090	.038	.000	.02	4	130	−

Mississippi River:																		
Above Schoolcraft River[a]	Feb. 27	18	2 m.	<7	.5	0	280		1.0	301	18	0.100	0.370	Trace.	0.03	28	450	−
Below Lake Bemidji[a]	...do....	18	2 v.	....	7	0	214		0	240	14	.190	.034	.000	.01	10	325	−
Below Lake Winnibigoshish[a]	Feb. 26	18	0	<7	9	0	186	172	0	209	16	.300	.054	.000	.05	10	120	−
Above Grand Rapids[a]	Feb. 25	18	0	<7	1.2	0	181	160	Trace.	217	13	.308	.066	.001	.06	9	200	−
Below Grand Rapids[a]	...do....	18	0	<7	1.2	0	181	146	Trace.	211	13	.302	.064	.001	.06	10	200	+
Above Mud River[a]	Mar. 1	40	1 v.	7	1.	0	170	154	0.5	198	9	.234	.066	.002	.04	13	1,600	+
Above Brainerd[a]	Feb. 28	40	1 v.	10	1.0	0	160	142	.5	182	12	.230	.073	.002	.04	11	4,200	+
Waterworks, Brainerd[a]	...do....	40	1 v.	10	1.4	0	161	142	.5	185	14	.256	.051	.002	.04	11	475	−
Below Brainerd[a]	...do....	40	1 v.+1m.	10	1.8	0	162	142	.5	188	17	.300	.068	Trace.	.04	11	12,500	+
Above Rum River[a]	Mar. 14	22	2 v.	10	1.8	5 est.	163	169	.5	201	16	.220	.050	.000	.14	9	425	−
Below Rum River[a]	...do....	22	2 v.	10	2.6	5 est.	194	79	.5	234	12	.206	.205	.000	.14	11	1,000	−
Above Minneapolis[c]	Mar. 16	20	.....	....	1.8	.....	160	[d]18	.....	220	[e]86	.312	.109	Trace.	Trace.	.....	100	+
Tributaries:[a]																		
Mud River at waterworks, Aitkin	Mar. 1	60	1 v.	10	1.8	0	108	97	Trace.	154	21	.412	.080	Trace.	.05	11	1,800	−
Rum River above asylum at Anoka	Mar. 14	25	3 v.	<7	2.	Trace.	145	114	Trace.	176	14	.252	.160	.000	.16	8	1,200	−
Rum River at Anoka waterworks	...do....	25	3 v.	<7	2.7	Trace.	146	120	Trace.	189	23	.250	.170	.000	.16	9	2,800	−
Rum River below Anoka	...do....	25	3 v.	<7	2.	Trace.	146	112	Trace.	173	18	.246	.160	.000	.19	9	6,500	−
Sewage effluent at Anoka asylum	...do....	40	5 fe.	15	3.	15 est.	196	250	1.0	393	85	.552	13.42	.010	.56	9	340,000	+
Leech Lake at Walker	Feb. 28	4	0	<	1.	Trace.	180	172	0	206	16	.220	.027	.000	.03	7	120	−

[a] Chemical analyses by R. B. Dole.
[b] Bacteriological examinations by Dr. E. H. Beckman.
[c] Chemical analysis by A. D. Meeds; bacteriological examination by Dr. J. F. Corbett.
[d] Temporary.
[e] Volatile.

The high nitrogen content, the vegetable odor, the color, and the fact that the albuminoid ammonia was separated with difficulty indicate that the stream contains a large amount of vegetable matter. These sanitary examinations show the futility of attempting to demonstrate the pollution of a stream of this character by chemical analysis of samples taken above and below settlements on its banks. The considerable amount of vegetable matter that is probably present completely masks the much-diluted but still dangerous sewage contributed by the towns and prevents its detection. Besides this difficulty, the tests indicate only an increase or a decrease in the amount of organic matter, without showing whether it is dangerous or harmless. Therefore the nitrogen determinations do not show the hygienic value of the stream. They do, however, demonstrate the presence of much organic matter, mostly in the undecomposed or "albuminoid" form. Free ammonia is generally about 0.05 part per million, but varies within wide limits. A small amount of nitrates is usually found; nitrites are seldom present except in winter and then only in small quantity; the greater part of the organic matter is determined as albuminoid ammonia. The water has a vegetable odor, combined sometimes with a moldy smell. It has at all times a distinct brown color, which runs as high as 160 parts per million, though its usual range is from 20 to 80. It has been suggested that the color is due to some compound of iron; but this can hardly be the case, because the small amount of this element present could not account for the high tint observed. It is probably caused by swamp drainage and resins extracted from the logs floated in the stream. The highest color is found in waters coming from swamp districts or in streams on which extensive logging operations are conducted, and the lowest in the large lakes, where opportunity is afforded for oxidation and destruction of the dissolved organic matter. The drainage of swamp lands and the decline of the lumber industry will therefore be accompanied by a progressive decrease in the color of the streams in this basin.

In mineral content the stream presents distinct characteristics. Chlorine is low, seldom exceeding 2 parts per million. A small amount of combined sulphuric acid, varying from a trace to about 5 parts per million, is present. Calcium and magnesium occur in appreciable quantities, as is shown by the alkalinity and total hardness. They are probably present as bicarbonates, since the samples examined gave no alkaline reaction with phenolphthalein in the cold. The fact that only a small percentage of the residue is soluble in alcohol shows that the water contains but a small amount of alkaline salts, though its content of alkaline-earth compounds is comparatively high. These statements are corroborated by the mineral analyses given in Table 28.

TABLE 28.—*Mineral analyses of water from upper Mississippi River basin.*[a]

[Parts per million.]

Place.	Date.	Total solids.	Suspended solids.	Organic and volatile.	Total alkalinity (as $CaCO_3$).	Oxide of iron and alumina Fe_2O_3+ (Al_2O_3).	Iron (Fe).	Aluminum (Al).
Mississippi River:								
At Brainerd[b]	Aug. —,1884	[c] 195					2.0	2.1
At Little Falls[d]	Mar. 31,1903		12		151	3.4		
At St. Cloud[d]	do		21		152	4.4		
Above Minneapolis[e]	Dec. 20,1881	[f] 212		24			.4	
Below Minneapolis[e]	do	[f] 211		34			1.3	
At Minneapolis[g]	Dec. 10,1890	215				7.5		
At Minneapolis[g]	Mar. 29,1900	188						
Rum River at Anoka[d]	Mar. 27,1903		10		197	1.0		
Sauk River at Sauk Center[d]	Mar. 31,1903		8		206	Trace.		
Platte River at Royalton[d]	do		49		198	3.4		
Millelacs[e]	1881	186		42			1.7	
Lake Minnetonka[h]	May 2,1883	[i] 110					Trace.	

Place.	Date.	Silica (SiO_2).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Chlorine (Cl).	Sulphate radicle (SO_4).	Carbonate radicle (CO_3).
Mississippi River:									
At Brainerd[b]	Aug. —,1884	18	44	20	10	3.4	0.9	2.0	90
At Little Falls[d]	Mar. 31,1903	4.3	43	13	8		12	9	90
At St. Cloud[d]	do	5.8	45	14	16		24	9	96
Above Minneapolis[e]	Dec. 20,1881	13	44	15	3.3	1.4	1.6	3.2	105
Below Minneapolis[e]	do	17	42	12	2.3	1.3	1.9	3.5	94
At Minneapolis[g]	Dec. 10,1890		50	18	6.7		4.8	3.1	124
At Minneapolis[g]	Mar. 29,1900		40	13					98
Rum River at Anoka[d]	Mar. 27,1903	18	50	17	7.3		12	.8	118
Sauk River at Sauk Center[d]	Mar 31,1903	5	47	25	3.9		6	13	124
Platte River at Royalton[d]	do	9	58	14	9		6	17	118
Millelacs[e]	1881	4.3	22	16	9.6	3.2	.8	1.2	85
Lake Minnetonka[h]	May 2,1883	4.8	28	8	1.1	2.6	.8	Trace.	64

[a] Expressed by analysts in hypothetical combinations; recomputed to ionic form at U. S. Geological Survey.
[b] Analysis by C. F. Sidener.
[c] Traces of NO_3 and PO_4.
[d] Analyses by Kennicott Water Softener Company.
[e] Analyses by J. A. Dodge.
[f] Trace of NO_3.
[g] Analyses by Chicago, Milwaukee and St. Paul Railway Company.
[h] Analysis by W. A. Noyes.
[i] Traces of lithium, phosphates, borates, and nitrates.

This portion of Mississippi River is distinctly different from the lower part, especially in its percentage of suspended matter and alkaline salts. Its use in boilers causes no serious difficulties, and it may be classed as good for steaming purposes. The calcium and magnesium compounds can be removed by using small amounts of soda ash. The water is harder than that of St. Louis River or that of St. Croix River and softer than the waters of Minnesota and Red rivers. The two latter streams also contain a higher percentage of alkaline salts than the upper Mississippi.

The bacterial content is of course extremely variable, and no average can be calculated logically from the data at hand. The amounts recorded probably indicate more nearly the actual condition of the stream than such figures usually do, because the samples were plated immediately after collection instead of after shipment to the laboratory. The water from the upper section of the system contained

from 100 to 500 bacteria per cubic centimeter, while some samples from the lower river contained as high as 3,000 to 6,000 per cubic centimeter. Though this rise in the number of bacteria shows that the water is open to suspicion as a source of domestic supply, the most positive index of pollution is the fact that from almost every sample examined between Grand Rapids and Minneapolis *B. coli communis* was isolated in pure culture with 1 cubic centimeter of water. The constant presence of this intestinal organism proves that the stream is unfit for domestic consumption in its natural state. In February, 1902, a culture of *B. coli communis* that was virulent for guinea pigs in small doses in twelve hours was isolated from the St. Cloud water supply, which is raw Mississippi River water. The importance of this fact is increased when it is stated that the total number of colonies was 50 per cubic centimeter, over 90 per cent being *B. coli communis*. A series of samples taken by the Minneapolis department of health from Brainerd to Minneapolis show that large numbers of this bacillus are constantly present in the river.[a] It is especially worthy of note that the organism was frequently found in other streams of the basin while it was not isolated from samples of water taken from the large lakes.

Mud and Rum rivers carry considerably less dissolved mineral matter than Mississippi River, as is shown by their alkalinity, hardness, and total solids. Millelacs is similar to Rum River at Anoka in its mineral constituents. On the other hand, Leech, Winnibigoshish, Cass, Bemidji, Carlos, Osakis, Latoka, and Hale lakes, all lying within the limits of the Cretaceous rocks, have high mineral contents. The influence of the Cretaceous rocks may also be seen by consideration of the river analyses in series. The mineral constituents in the river above Bemidji are highest; from that point downstream the alkalinity, hardness, and total solids decrease in every series, a change that shows the effect of dilution by waters from the regions comprising Archean and Cambrian rocks. In the same journey the water increases perceptibly in turbidity and in content of organic matter.

A comparison of the analyses of the five series of samples (Table 27) shows the seasonal variation in the water. In winter the inorganic substances are all higher than at any other time of year, as may be expected, since practically all the stream flow is derived from underground water which has been in more or less intimate contact with the mineral constituents of the ground. In the main stream the alkalinity is between 130 and 280 parts per million in winter, as compared with 60 to 180 parts in the spring and fall. There is a corresponding difference in chlorine, hardness, and total residue. During the winter the color, turbidity, and nitrogenous matter decrease noticeably.

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[a] Corbett, Dr. J. F., Typhoid and Water Supply: Ann. Rept. Minneapolis department of health. 1904, p. 27.

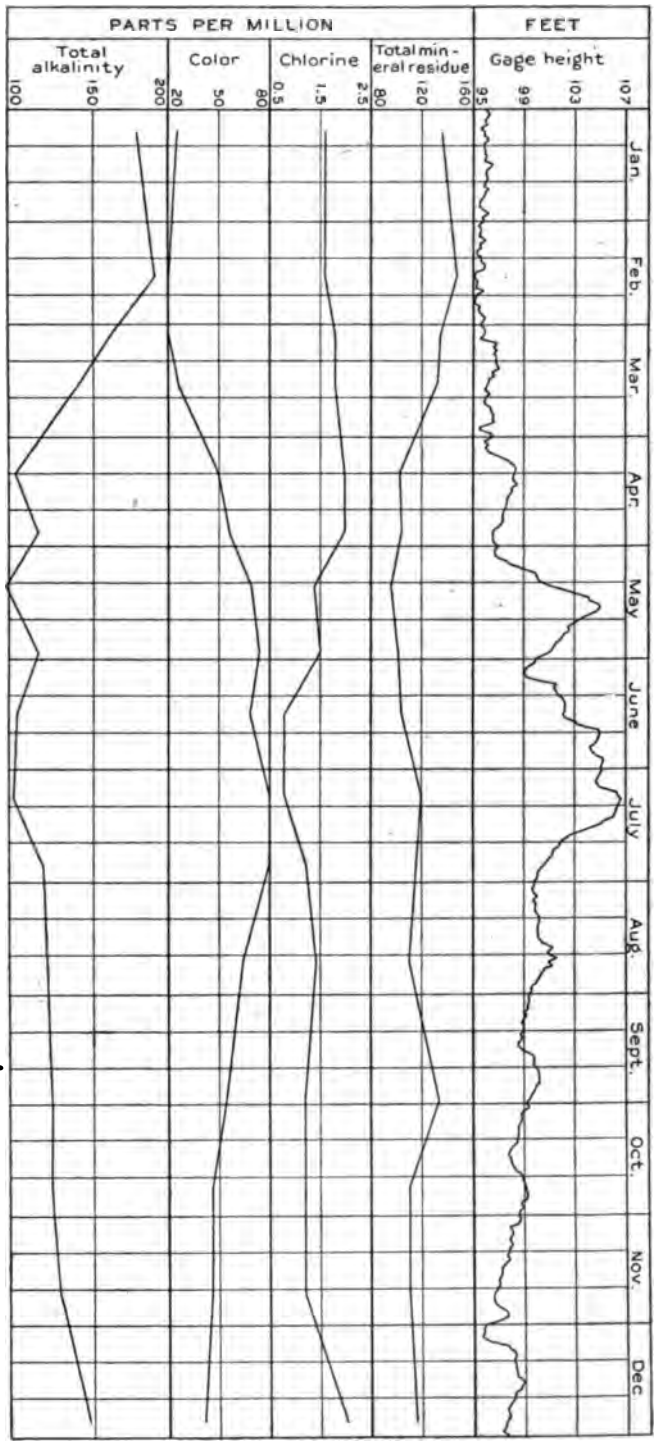


FIG. 2.—Diagram showing quality of Mississippi River water at Minneapolis, 1905, at different gage heights and seasons.

Though the number of bacteria per cubic centimeter suffers some diminution, *B. coli communis* is found as often in winter as in summer, a fact that indicates the constant presence of polluting matter. The presence of large numbers of these organisms in winter is not surprising when it is considered that the river is then practically a closed sewer from one settlement to the next, since its surface is covered with 10 to 40 inches of ice and the water is effectually protected from the purifying influences of sun and air.

TABLE 29.—*Quality of water of Mississippi River at Minneapolis, Minn., 1905.*[a]

[Parts per million.]

Date.	Total residue.	Volatile residue.	Fixed residue.	Sediment.	Color.	Chlorine.	Alkalinity.	Permanent hardness.	Oxygen consumed, 10 minutes boiling.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.
Jan. 6	231	95	136	Slight	25	1.60	173	18	5.48	0.192	0.090	Trace.	Trace.
Feb. 15	241	95	146	do	20	1.60	193	14	4.64	.169	.120	Trace.	Trace.
Mar. 3	220	86	134	do	20	1.80	160	18	5.28	.312	.109	Trace.	Trace.
Mar 16	206	74	132	do	25	1.80	150	19	5.52	.240	.088	Trace.	Trace.
Apr. 10	178	76	102	do	50	2.00	105	18	9.80	.468	.072	Trace.	Trace.
Apr. 26	175	72	103	Heavy	55	2.00	120	10	8.68	.298	.072	None.	Trace.
May 16	176	80	96	do	70	1.40	98	16	11.00	.416	.160	Trace.	Trace.
May 29	188	86	102	do	75	1.50	118	18	11.56	.420	.120	Trace.	Trace.
June 16	193	90	103	do	70	.80	105	15	11.08	.480	.088	None.	Trace.
July 7	204	84	120	do	80	.80	103	12	13.92	.640	.080	None.	Trace.
July 26	203	88	115	do	80	1.20	120	10	14.36	.336	.080	None.	Trace.
Aug. 22	188	78	110	do	65	1.40	123	6	12.08	.312	.060	None.	Trace.
Sept. 29	207	74	133	Moderate	55	1.20	128	14	9.92	.336	.072	None.	Trace.
Oct. 23	184	74	110	do	45	1.20	128	16	7.56	.298	.080	Trace.	Trace.
Nov. 21	181	70	111	do	45	1.20	133	19	6.88	.312	.038	Trace.	Trace.
Dec. 27	197	81	116	do	40	2.00	150	14	7.60	.240	.072	Trace.	Trace.

[a] Analyses by A. D. Meeds, Minneapolis, Minn.

The seasonal fluctuation in the quality of the water is shown in more detail by Table 29, which gives the results of analyses of Mississippi River at Camden Park pumping station, Minneapolis, during 1905. By means of fig. 2 a comparison may be made of the color, chlorine, alkalinity, and "fixed" or mineral residue with the river level at various times of the year. Acknowledgment is made to the department of health of Minneapolis for the analytical results. The gage heights, giving the change in level of the mill pond above the dam at St. Anthony Falls, have been obtained through the courtesy of Mr. R. D. Thomas, of the Minneapolis Mill Company. Color follows the gage height closely. In winter, when the swamps and other sources of vegetable matter are icebound, the color is lowest. It increases with the spring floods and follows the decline of the water in autumn, finally returning to its winter normal when the streams close. Chlorine and alkalinity, on the other hand, vary inversely with the depth of water. They are highest in winter, when the ground flow constitutes the greater part of the run-off and decrease during the

open season in proportion to the dilution caused by freshets. The relation of the total mineral solids to the discharge is not so simple, because that estimate includes both dissolved and suspended inorganic solids. Therefore the dilution of dissolved mineral matter during freshets is to some extent modified by an increase of turbidity.

The examinations noted in the preceding tables support the conclusions reached by sanitary inspection. It is evident that Mississippi River in its raw state is not a safe source of municipal supply. It is not, however, so grossly polluted as to be incapable of purification by well-operated filters. At the same time it is the most desirable source of supply for general use on account of its softness as compared with local well waters. In conclusion, the averages of 64 analyses of waters of upper Mississippi River are given in Table 30, which shows the maximum and minimum determinations made.

TABLE 30.—*Summary of quality of water of upper Mississippi River.*

[Parts per million.]

Determination.	Maximum.	Minimum.	Average.
Color	160	4	50
Odor			2 v
Turbidity	55	<7	<7
Chlorine	2.6	0.2	0.9
Sulphate radicle	[a] 5	0	Trace.
Alkalinity	280	64	151
Total hardness	229	83	136
Iron	1.5	Trace.	Trace.
Total residue	301	128	189
Soluble residue	25	7	16
Free ammonia	.370	.01	.191
Albuminoid ammonia	.95	.09	.475
Nitrates	.14	Trace.	.05
Nitrites	.002	Trace.	.000

[a] Estimated.

NOTES ON MUNICIPALITIES.

Thirty-four of the 42 settlements described below have public water supplies, 16 of which are derived from lakes or streams without purification. Twelve have sanitary sewerage systems. In all of them privies and cesspools are common and generally no particular restrictions are observed in their construction or care. Garbage is usually hauled outside the settlement limits and either burned or allowed to decay.

Aitkin, Aitkin County.—On left bank of Mississippi River at its confluence with Mud River. Water supply is taken from Mud River without filtration within the village limits. The stream is exposed to several sources of pollution and there was considerable typhoid fever in 1904. Ice supply is taken from Mud River above pumping station. Sewerage system, both storm and sanitary, enters Mississippi River. Private sewers also enter Mud River below the pumping station. Garbage is hauled away to the public dumping ground.

Akely, Hubbard County.—On Crow Wing River near its headwaters. Water for fire protection only is supplied by Red River Lumber Company. Water for domestic use is taken from shallow private wells. Ice is cut from Crow Wing Lake, 1 mile from town. There is no sewerage system, so that cesspools and privies are common. Garbage is hauled one-half mile from town and burned.

Alexandria, Douglas County.—Lakes Agnes and Winona border on the village and drain to Long Prairie River. Water supply is derived from a dug well in town, 30 feet deep by 20 feet diameter, sunk in gravel. The surroundings of the well are extremely unsanitary. Ice supply is taken from Lake Henry and Lake Latoka. A storm sewer enters Lake Agnes, as well as one or two private sewers, though there is no public sanitary sewerage. Garbage is hauled outside the city limits.

Anoka, Aitkin County.—On Mississippi River at the confluence with Rum River. Water supply is taken from Rum River without filtration; ice supply from the same source. A municipal sewerage system, both storm and sanitary, has recently been established; it discharges into Rum River just above its mouth. Garbage is hauled outside the city limits and burned. The First State Asylum for the Insane (300 inmates) is located less than 1 mile above the waterworks intake, on the west bank of the river. It has a private water supply from shallow wells and a private sewerage system with a septic tank and intermittent contact beds and sand filters discharging into Rum River above waterworks.

Bemidji, Beltrami County.—On west shore of Lake Bemidji, about 50 miles below Lake Itasca. Water supply is obtained from five 3½-inch points, driven 106 feet deep, on west side of the village at the edge of a swamp partially filled in with manure. Ice supply is taken from Lake Bemidji. Two private sewers, one from Markham Hotel and one from the hospital, enter Lake Bemidji in front of town. A public system has not yet been constructed, though a septic tank discharging into Mississippi River before its entrance into Lake Bemidji is contemplated. Garbage is hauled away and burned.

Brainerd, Crow Wing County.—On Mississippi River, 11 miles above the entrance of Crow Wing River. Water supply is derived from Mississippi River in front of the city, about 1 mile below a groundwood pulp mill. Two Jewell pressure filters are installed, but their capacity is not equal to the daily consumption and they are seldom used. The supply is subject to evident pollution from houses and industrial plants above it. Much of the drinking water consumed in town is obtained from a flowing well about 1 mile from town, the water being peddled in carts. Ice supply is obtained from Rice Lake, above city. Less than half the city is equipped with sanitary sewerage. On one of the main sewers purification has been attempted by

means of a long wooden box with baffle boards at each end. No test has been made of its efficiency. The other sewers discharge raw sewage. Garbage is hauled to dumping ground outside the city limits.

Buffalo, Wright County.—On Buffalo Lake, which is connected with the north branch of Crow River. It has no waterworks or sewerage. Ice supply is obtained from Buffalo Lake. Garbage is hauled to the dumping ground and covered with dirt.

Cambridge, Isanti County.—On Rum River, 30 miles below Princeton. Water supply is derived from a well 140 feet deep by 8 inches diameter, which draws water from a sandstone struck at 115 feet. Ice supply is obtained from Lake Fanny. No sewerage. Garbage is hauled outside city limits.

Cass Lake, Cass County.—On west shore of Cass Lake, near foot of Pike Bay. Water supply is obtained from 4 wells driven 28 feet in sand to clay. They have unsanitary surroundings and show evidence of pollution. Ice supply is taken from Cass Lake. A sanitary sewerage system discharges into a creek entering Pike Bay.

Cokato, Wright County.—Drainage goes to a marsh that is ditched to Sucker Creek. No waterworks or sewerage. Ice supply obtained from Brooks Lake.

Deer River, Itasca County.—One mile north of Mississippi River on Deer River. Water supply obtained from a flowing well 96 feet deep, with a 3-inch casing, driven through sand, quicksand, and blue clay into water-bearing gravel. No sewerage.

Delano, Wright County.—On the south branch of Crow River. Water supply obtained from the river; used only for fire protection and for sprinkling, and not filtered. Ice supply cut from Lake Rebecca. Garbage burned. No sewerage.

Elk River, Sherburne County.—On Elk River at its junction with Mississippi River. No waterworks or sewerage. Drinking water is generally obtained from private artesian and driven wells; ice supply from both rivers. Garbage is burned or hauled out in the country.

Excelsior, Hennepin County.—On Lake Minnetonka. Chiefly a summer resort and has but small constant population. No waterworks or sewerage. About 5,000 tons of ice are harvested on the lake for local use and for shipment to Minneapolis. There is no public garbage disposal.

Fort Snelling, Hennepin County.—A military reservation with accommodations for about 1,500 men on west bank of Mississippi River at its confluence with Minnesota River. Water for general use is obtained from a 10-inch artesian well 636 feet deep drawing its supply from the sandstone. Separate storm and sanitary sewerage systems discharge into both rivers. The ice supply is cut on Minnesota River just above the post.

Glencoe, McLeod County.—On Buffalo Creek. Water supply obtained from one 8-inch well drilled 1,728 feet deep, drawing its supply from sand rock. Ice supply is taken from an artificial basin fed by artesian wells and connected with the creek most of the year. No sewerage. No regular garbage disposal.

Grand Rapids, Itasca County.—On Mississippi River just below Pokegama Falls. Water supply is taken without filtration from Half Lake, which may perhaps receive surface drainage from several dwellings and farms. Ice supply is cut from Forest Lake, 1 mile west of the village. Sewerage system discharges into a small creek, thence into the river. Garbage is hauled to dumping ground.

Grove City, Meeker County.—Is connected with Crow River by a slough north of town. Water supply is obtained from an 8-inch well sunk 740 feet deep; ice supply from a small lake 3 miles north of town. No sewerage.

Hector, Renville County.—Drained by a county ditch to the south fork of Crow River. Water supply obtained from an 8-inch drilled well 420 feet deep; ice supply from an artificial pond fed by wells. Storm sewerage, but no sanitary system has been established.

Hutchinson, McLeod County.—On South Fork (locally called Hassan River) of Crow River, near Otter Lake. Water supply is obtained from an artesian well 10 inches diameter, driven 60 feet to rock, then drilled 100 feet; ice supply from Crow River above city drainage. A sanitary sewerage system empties into Crow River. Garbage is dumped into a pit outside the city limits.

Litchfield, Meeker County.—Drains to Jewett Creek, the outlet of Lake Ripley, which enters north branch of Crow River. Water supply is obtained from 2-inch wells driven 42 feet in the drift; ice supply from Lake Ripley. No sewerage. No regular garbage disposal.

Little Falls, Morrison County.—On Mississippi River, 38 miles above St. Cloud. Water supply is procured from Mississippi River without filtration; ice supply from the river opposite the city. Sanitary sewage is discharged into Mississippi River. Garbage is hauled outside city limits to dumping ground.

Long Prairie, Todd County.—On Long Prairie River. Water supply is obtained from two dug wells, one 12 feet in diameter by 20 feet deep, the other 30 feet in diameter by 40 feet deep. Ice supply is cut from Lake Charlotte, south of the village. No sewerage. Garbage is generally dumped in hollows and covered with dirt.

Melrose, Stearns County.—On Sauk River, 20 miles below Sauk Center. Water supply for fire protection only is taken from Sauk River. Drinking water is procured from private driven or dug wells; ice supply from Sauk River, above the dam. No sewerage. Garbage is hauled outside the city limits.

Milaca, Millelacs County.—On Rum River, 15 miles above Princeton. Water supply for fire protection only is obtained from Rum River; ice supply from Rum River. A combined sewerage system empties into Rum River below the village. Garbage is hauled to the village dumping ground.

Minneapolis, Hennepin County.—On both sides of Mississippi River, about 9 miles above its confluence with Minnesota River. The city water supply is taken unfiltered from Mississippi River by four intakes: (*a*) north station, at Camden Park, near the upper city limits; (*b*) northeast station, at foot of Thirty-seventh avenue NE., before the river enters the city; (*c*) east-side station, and (*d*) west-side station, in the heart of the city, below several sewers. The lower stations have been closed by the water board. The present supply has been repeatedly condemned by sanitary experts, who recommend filtration. The city ice supply, amounting to more than 150,000 tons annually, is cut from all the numerous lakes in Hennepin County, among which are lakes Amelia, Big, Calhoun, Cedar, Clearwater, Crystal, Twin, and Waconia. Storm and sanitary sewerage systems extend throughout the greater part of the city, discharging into Mississippi River by several outlets. Privies and cesspools, which must have water-tight vaults, are permitted only where there is no access to sewers. Garbage is burned at a crematory owned and operated by the city.

Monticello, Wright County.—On Mississippi River, 26 miles above the mouth of Rum River. Water supply is obtained from an artesian well 8 inches in diameter by 237 feet deep in the drift; ice supply from First Lake, west of the village, and from the river. No sewerage system or regular garbage disposal.

New London, Kandiyohi County.—On Middle Fork of Crow River. Waterworks for fire protection only. No sewerage; ice supply from lakes Green and Andrew and from the river.

Osakis, Douglas and Todd counties.—At the south end of Lake Osakis. Water supply for fire protection and for sprinkling is taken from the lake; drinking water is commonly taken from shallow driven wells. Ice supply is cut from Lake Osakis. Limited storm sewerage is established.

Park Rapids, Hubbard County.—On Fishhook River, about 2 miles below Fishhook Lake. Water supply and ice supply are both taken from the river. The village water is little used for domestic purposes. No sewerage. Garbage is hauled to the public dumping ground.

Paynesville, Stearns County.—On North Fork of Crow River. Water supply is obtained from four 3-inch wells driven 80 feet in the drift; ice supply from Lake Koronis south of town. No sewerage. Garbage is dumped on convenient vacant property.

Princeton, Millelacs County.—On Rum River about 100 miles above its mouth. Water supply is taken from one tubular well, 8 inches diameter by 187 feet deep, in the drift; ice supply from Rum River. No sewerage.

Royalton, Morrison County.—On Platte River, 7 miles above its confluence with Mississippi River. Ice is cut from the river. Garbage is carted to the village dumping ground. No waterworks or sewerage system.

St. Cloud, Benton, Sherburne, and Stearns counties.—On Mississippi River 76 miles above Minneapolis and 2 miles below the entrance of Sauk River. Water supply is taken without filtration from Mississippi River near the upper edge of the city. It is grossly polluted and has been pronounced unsafe by the State board of health. The part of the city on the west bank of the river discharges sewage into the river by 5 main sewers, both storm and sanitary. East St. Cloud is not sewered. The Minnesota State Reformatory, with about 200 inmates, is just below the city, on the east bank of the river. Its water supply is taken from 4 shallow wells in an old river bottom east of the reformatory grounds. The buildings are completely equipped with sewerage, which discharges into Mississippi River.

St. Louis Park, Hennepin County.—A suburb of Minneapolis, situated on Minnehaha Creek. The ice supply is cut from the creek and from Lake Calhoun. No waterworks, sewerage, or systematic garbage disposal.

Sauk Center, Stearns County.—On Sauk River. Water supply is derived from Sauk River just above the mill dam, opposite the city, without filtration. It is little used for domestic purposes. The ice supply is taken from the river above the city. Sanitary sewerage discharging into Sauk River is established. Garbage is hauled outside the city limits and dumped.

Sauk Rapids, Benton County.—On Mississippi River, opposite the confluence of Sauk River, 2 miles above St. Cloud. Ice is cut from Mississippi River. No waterworks or sewerage. Garbage is generally hauled away by farmers.

Staples, Todd County.—Connected by a small creek with Crow Wing River. The ice supply is from Dower Lake, 2 miles west of the village. Garbage is taken to high sandy ground 2 miles east of town. No waterworks or sewerage.

Wadena, Wadena County.—On Union Creek 2 miles south of Leaf River. Water supply is obtained from a well, 22 feet deep by 20 feet in diameter, in the center of the village. Ice supply is cut from Union Creek and from Leaf River. No sewerage. Garbage is hauled to the public dumping ground.

Walker, Cass County.—On the west shore of Leech Lake. Water and ice supplies are taken from the lake in front of the town. The water is not filtered. No sewerage is established. Garbage is burned.

West Minneapolis (Hopkins), Hennepin County.—A short distance southwest of Minneapolis. Drains to Minnehaha Creek. Water for fire protection only is furnished by the Minneapolis Threshing Machine Company from an 8-inch well 600 feet deep. Ice is cut on Shady Oak Lake. No sewerage. Garbage is usually hauled away by market gardeners.

White Bear Lake, Ramsey County.—On the west shore of White Bear Lake, which discharges through a chain of lakes and Rice Creek into Mississippi River. It is a summer resort with a comparatively small permanent population. A 10-inch well for a village supply has been recently put down. No sewerage. Garbage is hauled outside the village limits and dumped.

MINNESOTA RIVER BASIN.

GENERAL DESCRIPTION.

Boundaries.—The basin lies across the southern third of Minnesota and includes also small portions of Iowa and South Dakota. It is bounded on the north by upper Mississippi and Red River drainage areas; on the east by lower Mississippi area and the basin of Cedar River; on the south by Des Moines River basin, and on the west by several small streams tributary to Missouri River. (Pl. III.)

Course and slope of Minnesota River.—Minnesota River rises on the eastern slope of the Dakota foothills (Coteau des Prairies), in the northeastern part of Marshall County, S. Dak., about 30 miles west of Lake Traverse, at an approximate elevation of 1,896 feet above sea level (Nicollet). It flows southeastward to the State border, where it falls rapidly to the level of Bigstone Lake. The stream is a mere mountain torrent in this upper section, where the bed is often entirely dry. Bigstone Lake is about 30 miles long and 1 to 2 miles wide. Its east and west shores are well defined by gravel bluffs that rise abruptly 150 feet to the level of the surrounding prairies. The lake is narrow and shallow, exceeding 15 feet in depth at only a few places. Pleasure craft and other small steamers ply on the lake, and there is regular water communication between Ortonville and Browns Valley during the open season. At its upper or northern end, where Minnesota River enters, a marshy strip, not over 20 feet high, stretches northward 5 miles to the equally swampy southern extremity of Lake Traverse, the headwaters of Bois de Sioux River. At Ortonville the Minnesota River emerges from the southern extremity of Bigstone Lake and, after uniting with Whetstone River, which enters from the south, flows southeastward to Mankato, a distance of 150 miles. Though there are some stretches of still water between Ortonville and Mankato, the river riffles over granitic rocks at several places and is not navigable. Blue Earth River enters from the south just above Man-

kato, where the main stream turns abruptly and pursues a northeasterly course to its mouth. The lower portion, which has an average width of 300 feet, is navigable by light-draft vessels for 37 miles from its mouth to Little Rapids.

In the first 40 miles of its course the stream falls 900 feet, having an average slope of 25.4 feet per mile. (See fig. 3.) After passing 24 miles through Bigstone Lake it drops, by series of rapids alternating with reaches of still water, to Little Rapids, with an average slope of 1.25 feet per mile. Excluding the principal drop of 50 feet in 5 miles at

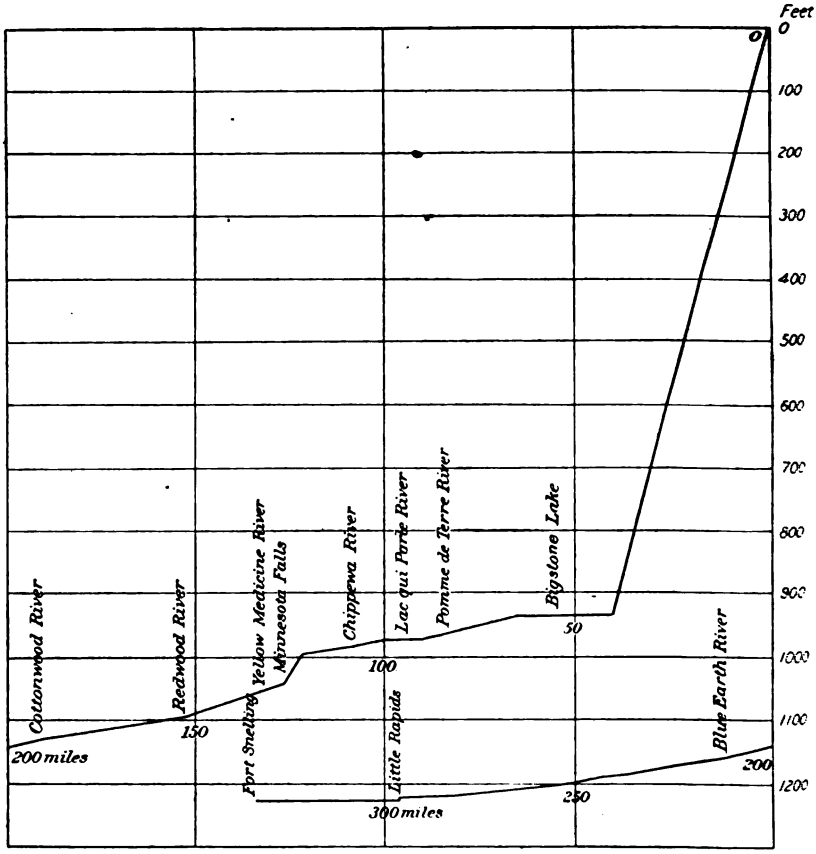


FIG. 3.—Profile of Minnesota River.

Granite Falls, this section has a grade of 1.06 feet per mile. Below Little Falls, after an abrupt descent of 2 feet, the slope is less than 0.1 foot per mile. If the small stream above Bigstone Lake is excluded, the mean slope of Minnesota River is considerably less than that of upper Mississippi River.

Tributaries of Minnesota River.—The principal affluents of the Minnesota are Pomme de Terre River, Chippewa River, and Hawk Creek

from the north, and Whetstone, Lac qui Parle, Redwood, Cottonwood, and Blue Earth rivers from the south, all of which enter above Mankato. (See Pl. III.) The largest tributary is Blue Earth River, which rises in Kossuth County, Iowa, and flows northward as a meandering prairie stream. It is about 60 feet wide at its mouth and 2 to 3 feet deep during ordinary stages. Below the mouth of Blue Earth River near Mankato the Minnesota drains a comparatively narrow area, its tributaries being small and insignificant. Around the headwaters of Pomme de Terre and Chippewa rivers there are many lakes, and throughout the entire valley there are small bodies of water that lie in shallow depressions of the drift and are fast being eliminated by silting, artificial drainage, and other factors.

Topography.—The Coteau des Prairies, in the southeastern part of the area, slopes rather steeply and evenly to the plain forming the valley of the Minnesota. Except for this feature the entire region is a rolling prairie crossed by the deep, wide bed of the river. Formerly some lumbering was done in the extreme northern part, but now the forests are gone. On account of the absence of woods and of large lakes capable of retaining flood waters, the streams rise rapidly after rains or thaws and become very turbid, for they easily disintegrate the unprotected clayey gravels along their banks.

Geology.—Gneisses, schists, and granites are exposed along the deeply eroded valley of the river from New Ulm to Lac qui Parle. Red quartzite is found in the southern part of the valley, through Cottonwood, Watonwan, and Jackson counties. Limestones, shales, and sandstones of Cambrian and Ordovician age reach as far west as the valley of Blue Earth River and occupy the eastern part of Minnesota Valley. The most widespread deposits, however, are the Cretaceous rocks, which extend eastward from the Dakotas and cover about two-thirds of the basin, including all of its western part except some small areas, in which there are exposures of earlier rocks. These extensive deposits and the many scattered Cretaceous beds found in the eastern section of the valley have undoubtedly a modifying influence on the composition of the drift and consequently on the drainage. The more or less stratified materials of the Pleistocene overlie the earlier rocks throughout the entire region.

When Lake Agassiz, a glacial lake, occupied the valley of Red River its outlet, to which the name Warren River has been given, extended through the valley in which Traverse and Big Stone lakes and Minnesota River are now situated. This river cut a channel 150 to 200 feet deep and from 1 to 2 miles wide across the valley. Before Lake Agassiz was formed a body of water gathered in this basin at the margin of the receding ice sheet, extending from Big Stone Lake to Waseca and comprising an area of more than 3,000 square miles. This great lake, which has been called Lake Minnesota, found an out-

let southward through Blue Earth River to Des Moines River.[a] Lacustrine gravels, sands, and clays, having a thickness of more than 100 feet in some places in the central part of the valley, testify to the existence of this prehistoric lake.

Soil and subsoil.—The top layers of the drift in this region differ distinctly from those of upper Mississippi Valley in their content of certain mineral constituents. The following table gives the average composition of soils in Minnesota Valley as computed from analyses made by the Minnesota agricultural experiment station:

TABLE 31.—*Chemical composition of soil and subsoil in Minnesota.*

	Surface soil.		Subsoil.	
	Minnesota River basin.	Entire State.[a]	Minnesota River basin.	Entire State.[a]
Insoluble in HCl	76.65	79.92	76.77	82.41
Volatile	9.75	8.98	6.10	5.33
Potassium oxide (K_2O)	.39	.43	.38	.40
Sodium oxide (Na_2O)	.25	.45	.30	.32
Calcium oxide (CaO)	1.43	1.29	6.64	1.78
Magnesium oxide (MgO)	.80	.61	.55	.80
Oxides of iron and aluminum ($Fe_2O_3+Al_2O_3$)	7.87	7.20	8.89	8.32
Phosphoric anhydride (P_2O_5)	.22	.20	.20	.17
Sulphuric anhydride (SO_3)	.13	.10	.08	.06
Carbonic anhydride (CO_2)	.75	.62	1.36	.93

[a] Snyder, H., Characteristic features of Minnesota soils: Bull. 65, Agr. Exp. Sta., University of Minnesota, Chem. Div., Nov., 1899, p. 69.

The amount of sand is not excessive, the insoluble matter being lower than in the average soil in the rest of the State. Nearly all of the soluble constituents are present in larger amounts than the average, and the high percentage of these is in line with the high percentage of inorganic matter found generally in the water of Minnesota River. In their content of alkaline ingredients the soils lie midway between those of upper Mississippi Valley and those of Red River basin. The influence of the Cretaceous deposits and the difference in rainfall may cause this difference between the soils of these regions.

INDUSTRIAL POLLUTION.

The following list gives the number of establishments in this area having wastes of deleterious nature:

TABLE 32.—*Industrial establishments causing stream pollution in Minnesota River basin.*

Breweries	23
Creameries	45
Gas works	2
Sawmills	6
Woolen mill	1

[a] Upham, Warren, The Glacial Lake Agassiz: Mon. U. S. Geol. Survey, vol. 25, p. 264.

Four breweries are located at New Ulm and two at Mankato, the total output of all these amounting to about 6,000 barrels per month. Most of these establishments do their own malting. Their wastes, consisting of washings from floors, barrels, vats, etc., and of slop, after the brewer's "grains" have been screened out, are run into Minnesota River either directly or through sewers. The other establishments noted in the list above are all small and their wastes are not likely to be troublesome in the streams. Corn and wheat raising are the principal industries of the district. Drainage from the cultivated lands contains generally more suspended and dissolved matter than that from the other lands, because the tilled soils are less compact and therefore more easily disintegrated. In regions where manure is used more or less organic matter reaches the streams from the fields, especially during freshets.

MUNICIPAL POLLUTION.

POPULATION.

Table 33 shows the population by counties for three successive censuses in Minnesota River drainage area. There are 26 inhabitants per square mile, about the average density of the State (see Table 34). Since this region is essentially a farming country the population is chiefly in the rural districts and is evenly distributed over the entire area, except possibly a small part above Ortonville, which is not now open for settlement. This portion of the State was first to be developed and, on account of its remarkable fertility, rose quickly to its present population. It is probable that there will not be a great increase in the future but only the gradual growth incident to a rural region.

TABLE 33.—*Population in Minnesota River basin.*

County.	U. S. census, 1890.	U. S. census, 1900.	State census, 1905.
Bigstone	5,214	7,875	8,442
Blue Earth	29,210	32,263	31,228
Brookings, S. Dak	800	1,000	[a] 1,200
Brown	15,817	19,787	20,523
Carver	11,758	12,418	12,504
Chippewa	8,555	12,499	13,356
Codington, S. Dak	700	800	[a] 900
Cottonwood	5,012	7,835	8,286
Dakota	2,872	2,885	3,172
Deuel, S. Dak	2,200	3,300	[a] 4,000
Douglas	6,008	7,234	7,382
Faribault	16,708	22,055	20,448
Freeborn	4,885	5,779	5,592
Grant	3,438	4,468	4,826
Hennepin	1,728	1,912	2,087
Jackson	820	1,304	1,306
Kandiyohi	7,911	10,913	11,826
Lac qui Parle	10,382	14,289	15,182
Lesueur	15,667	16,462	16,479
Lincoln	4,552	7,173	7,990
Lyon	9,501	14,591	16,171

TABLE 33.—*Population in Minnesota River basin*—Continued.

County.	U. S. census, 1890.	U. S. census, 1900.	State census, 1905.
Martin	7,761	14,157	14,661
McLeod	2,432	2,800	2,739
Grant, S. Dak	6,814	9,103	[a] 11,000
Murray	631	1,103	1,088
Nicollet	13,382	14,774	14,994
Ottertail	3,878	4,946	5,210
Pipestone	100	323	323
Pope	8,151	10,288	11,035
Redwood	9,386	17,261	19,034
Renville	12,993	18,281	18,336
Rice	182	249	304
Roberts, S. Dak	1,200	8,000	[a] 11,000
Scott	13,831	15,147	15,094
Sibley	15,199	16,862	16,354
Steele	1,411	1,602	1,609
Stevens	4,454	7,366	7,773
Swift	10,161	13,503	13,575
Traverse	498	721	902
Waseca	11,663	13,027	12,085
Watonwan	7,746	11,496	11,494
Yellow Medicine	9,854	14,602	15,899
Kossuth, Iowa	2,763	4,952	4,729
Winnebago, Iowa	2,143	3,655	3,460
Total	310,371	411,060	425,568

[a] Estimated.

TABLE 34.—*Density of population in Minnesota River basin.*

	Drainage area.	Inhabitants per square mile.		
		1890.	1900.	1905.
	Sq. miles.			
Above Ortonville	[a] 1,232	2.9	8.1	8.7
Above Mankato:				
Entire area	[b] 13,400	16.6	23.6	24.8
Excluding chief settlements		14.3	19.6	20.8
Above Mississippi River:				
Entire area	[c] 16,350	19.0	25.1	26.0
Excluding chief settlements		15.7	20.4	21.4

[a] Ann. Rept. Chief of Engineers, U. S. Army, 1898, p. 1838.
[b] Water-Sup. and Irr. Paper No. 130, U. S. Geol. Survey, 1905, p. 53.
[c] Ann. Rept. Chief of Engineers, U. S. Army, 1894, pt. 3, p. 1704.

CONDITIONS ON THE MINNESOTA.

General conditions.—The drainage and general hydrography of the valley are exhibited in Pl. III, which shows also the location and the relation of all settlements having a population exceeding 1,000 according to the census of 1900. A vertical bar within the population circle indicates that a municipality has a public sewerage system. Unlike those of the upper Mississippi Valley, many of the centers of population are remote from running water. It does not follow from this, however, that the streams thus escape pollution. The general distribution of both city and rural population all over the area is sufficient to render any surface water within it unsafe.

Conditions at Ortonville.—Around the headwaters of the river above Ortonville the population is less dense than in any other part of the

basin. Sisseton and Browns Valley, the only settlements in this district, are both small. There is little pollution in this region.

Conditions at Mankato.—Over three-fourths of the Minnesota basin lies above Mankato. It is farming land, on which wheat and corn are the principal crops. One of the most noticeable features of this region is the number of small settlements distributed over it. New Ulm, the second city in size, is located on the river, a little over 20 miles above Mankato. The presence of this large place is sufficient to condemn the water of Minnesota River for domestic use at Mankato without filtration. The stream is often so muddy after heavy rains and thaws that the use of the raw water at such times is undesirable. The chief sources of stream pollution are given in the following table:

TABLE 35.—*Principal settlements in Minnesota River basin above Mankato.*

Name.	Stream.	Distance above Mankato.[a]	Population.		
			1890.	1900.	1905.
		Miles.			
Appleton	Pomme de Terre River	133	994	1,184	1,321
Benson	Chippewa River	138	877	1,525	1,766
Blue Earth	Blue Earth River	71	1,569	2,900	2,364
Canby	Canby Creek	161	470	1,100	1,505
Fairmont	Lake George	86	1,205	3,040	2,955
Glenwood	Lake Minnewaska	178	627	1,116	1,718
Granite Falls	Minnesota River	87	.....	1,214	1,340
Janesville	Lake Elysian	45	921	1,254	1,205
Lake Crystal	Crystal Lake	15	824	1,215	1,231
Madelia	Watonwan River	30	852	1,272	1,290
Madison	.....	146	625	1,336	1,604
Mapleton	Little Cob River	27	607	1,008	938
Marshall	Redwood River	106	1,203	2,088	2,243
Milbank, S. Dak	Whetstone River	161	1,207	1,426	.....
Montevideo	Chippewa River	103	1,437	2,146	2,595
Morris	.....	168	1,266	1,934	2,003
New Ulm	Minnesota River	22	3,741	5,403	5,720
Ortonville	do	149	768	1,247	1,612
Redwood Falls	Redwood River	63	1,238	1,661	1,806
Renville	Sacred Heart Creek	81	413	1,075	1,229
St. James	St. James Lake	43	939	2,607	2,320
Sleepy Eye	Sleepy Eye Creek	38	1,513	2,046	2,312
Springfield	Cottonwood River	116	716	1,511	1,546
Tracy	Branch of Cottonwood River	92	1,400	1,911	2,015
Waseca	Clear Lake	51	2,482	3,103	2,838
Wells	.....	51	1,208	2,017	1,814
Willmar	Hawk Creek	131	1,825	3,409	4,040
Winnebago	.....	66	1,108	1,816	1,553
Total urban population	.....	.....	32,035	53,564	54,883

[a] Mankato is 119 miles from the mouth of the river.

Conditions at mouth of river.—Minnesota River below Mankato is not used for any purposes other than navigation and ice harvesting. The following list of settlements in its basin gives their distances above the mouth of the river and their population. Many of these places have reached their maximum size, and some of them are even now on a decline, due to the inevitable reaction caused by a rush of pioneers to cheaper lands. This decline will probably be followed by a slower and more permanent growth, as has been the case with similar towns in the older Central States.

TABLE 36.—*Principal settlements in Minnesota River basin above Mississippi River.*

Name.	Stream.	Distance above mouth.	Population.		
			1890.	1900.	1905.
		Miles.			
Settlements above Mankato (see Table 35, p. 71)			32,035	53,564	54,983
Belle Plaine	Minnesota River	52	814	1,121	1,301
Chaska	do	30	2,210	2,165	2,065
Jordan	Sand Creek	40	1,233	1,270	1,311
Le Sueur	Minnesota River	82	1,763	1,937	1,842
Mankato	do	119	8,838	10,599	10,996
New Prague			955	1,228	1,419
St. Peter	Minnesota River	97	3,671	4,302	4,514
Shakopee	do	26	1,757	2,047	2,069
Total			53,276	78,233	80,420

TYPHOID FEVER.

Though typhoid fever is prevalent in Minnesota River Valley, no regular report of it has been made, so that detailed statistics can not be given. Mankato, New Ulm, Montevideo, and Ortonville all have had undesirable records of typhoid fever. Although there have been no extensive outbreaks, a number of cases are distributed over the area every year. Surface water is not extensively used for domestic supply, so that the spread of the fever is probably not due to infected streams. Many cases of the disease have been traced to the use of water from infected wells. Since modern improvements have not been adopted with extreme thoroughness, large sections of the principal cities are still unconnected with sewers, and the inhabitants have a general disinclination to abandon their private wells for municipal supplies. Consequently many driven or dug drift wells in close proximity to cesspools, privy vaults, and other foci of pollution are still in existence, and the use of water from these wells no doubt propagates this preventable disease. Typhoid fever will be eradicated only when the people generally are convinced that shallow wells in cities are as a rule unsafe sources of drinking water and offer much chance for the dissemination of specific diseases.

QUALITY OF WATER.

At the beginning of the work points were selected for the collection of samples above and below the principal settlements on the main stream and on Redwood River. Series I in Table 37 was collected during January and February, 1904, when the river was completely frozen and fluctuated little in its discharge. Series II was collected during the next winter under similar circumstances. Series III was collected when the ice was going out and, unfortunately, shows the stream under varied conditions at different points. The sample from Big Stone Lake was taken through the ice, just before the spring thaw. The samples at Granite Falls, New Ulm, and Redwood Falls were

taken while the ice was breaking up and probably show considerable dilution of the characteristic run-off. When the samples at Mankato were taken the river was in decided flood condition, standing somewhat over 4 feet above its winter level, and rapidly rising. The sample from Fort Snelling was also taken near the crest of a flood after the ice had left the lower river.

The stream carries a noticeable quantity of organic matter, as evinced by the nitrogen determinations. Albuminoid ammonia almost invariably exceeds 0.3 parts per million and free ammonia is likewise high. Nitrates are found in measurable quantity and nitrites are present, especially during flood time. The water has generally a slight vegetable odor, which during freshets is accompanied or overshadowed by an earthy or a musty smell. Though the water has some color, which is, as may be expected, highest during floods, it is not so high as that of surface water from regions where swamps and forest are more abundant.

In mineral content the waters of this region are distinctly different from those of upper Mississippi Valley. Chlorine is considerably higher, generally 3 to 10 parts per million, and often exceeds the latter amount. Sulphates vary from 70 to 450 parts per million and are also present in considerable quantity in other waters of the basin, as shown by Table 38, which gives the results of inorganic analyses of surface waters from divers sources. The total residue is high and the amount soluble in alcohol indicates the presence of considerable sodium and potassium. The inorganic determinations in these tables prove that there is an essential difference between the prairie stream Minnesota River and the woodland drainage of upper Mississippi Valley. The greatest distinction is in the amounts of sodium, potassium, and sulphuric acid. Though the surface waters are softer than those furnished by wells in the region, they still carry much mineral matter and prove troublesome when used in boilers in their raw state. The river is not so strongly mineralized as Red River, though it is similar to it in many respects.

The samples examined bacteriologically contained excessive numbers of bacteria. *B. coli communis* was isolated in pure culture from a majority of the samples, a fact indicating the unfitness of the water for domestic use without filtration. The waters of the tributaries, so far as they have been examined, are similar to the water of Minnesota River, as might have been expected, since they drain regions that are similar in geologic and economic conditions. The influence of the Cretaceous rocks is shown to some extent by a difference between the mineral content of the waters in the upper valley and that of Minnesota River at Fort Snelling, though the dilution is not so marked as in other rivers in the State.

TABLE 37.—*Quality of water in Minnesota River basin.*

[Parts per million.]

SERIES I, WINTER OF 1904.[a]

Source.	Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Total alkalinity.	Total hardness.	Iron as Fe.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Free CO_2.	Bacteria per c. c.	B. coli communis.
Minnesota River:																		
Bigstone Lake at Ortonville	Feb. 17				17.5		105	708				0.54	0.08	0.000	Trace.		225	−
Below Ortonville	do				17.0		112	666				.70	.09	.000	Trace.		65	−
Below Chippewa River	do				15.0		192	706				.79	.28	Trace.	Trace.		850	+
Above Granite Falls	Feb. 18				13.7		185	994				.55	.50	Trace.	Distinct.		550	−
Below Granite Falls	do				14.0		186	986				.71	.36	Trace.	Distinct.		475	−
Above New Ulm	Feb. 19				8.5		155	688				.41	.45	Trace.	Distinct.		550	
Below New Ulm	do				9.0		155	703				.45	.38	Trace.	Distinct.		1,400	+
Above Mankato	Jan. 7				4.2			620				.33	.30	Distinct.	Trace.		10,500	+
Below Mankato	do				4.8			606				.35	.308	Distinct.	Distinct.			
Tributaries:																		
Chippewa River above Montevideo	Feb. 17				4.0		195	708				.43	.445	Trace.	Distinct.			
Redwood River above Redwood Falls	Feb. 18				6.0		185	891				.23	1.06	Distinct.	Distinct.		100	−
Redwood River below Redwood Falls	do				6.0		185	898				.31	.73	Distinct.	Distinct.		850	+
Blue Earth River at mouth	Jan. 7							408				.18	.308	Distinct.	Distinct.		(b)	+

SERIES II, WINTER OF 1904-5.[c]

Source.	Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Total alkalinity.	Total hardness.	Iron as Fe.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Free CO_2.	Bacteria per c. c.	B. coli communis.
Minnesota River:																		
Bigstone Lake at Browns Valley	Dec. 4	4		15	12.4	457	223	584	0	933	365	0.530	0.156	Trace.	0.025	7	100	−
Minnesota River above Granite Falls	Dec. 5	25		<7	4.3	188	326	473	Trace.	618	89	.396	.122	0.000	.04	13	2,000	+
Minnesota River below Granite Falls	do	25		<7	5.0	201	321	473	Trace.	623	88	.480	.136	.000	.04	13	3,200	+
Minnesota River above New Ulm	Dec. 7	25		30	4.9	259	320	529	1.0	659	179	.490	.062	.000	.04	10	400	−
Minnesota River above Mankato	Dec. 8	18		19	4.5	207	322	529	1.0	619	172	.380	.070	.000	.04	13	300	−
Minnesota River above Mankato	Jan. 4	25	2 v.	15	4.5	207	380	640	1.0	728	184	.100	.220	Trace.	.09	18	600	−
Minnesota River below Mankato	Dec. 8	18		20	4.7	207	330	473	1.0	618	222	.400	.296	.000	.04	18	4,100	+
Minnesota River below Mankato	Jan. 4																4,200	+
Tributaries:																		
Redwood River below Marshall	Dec. 7	18		20	10.0	514	335	640	0	1,176	335	.340	1.40	.025	.18	19	3,100	+
Blue Earth River at mouth	Jan. 4	4	1 v.	7	3.5	71	311	473	Trace.	457	92	.352	.420	.000	.02	20	400	

SERIES III, SPRING OF 1905.[c]

Minnesota River:																		
Bigstone Lake at Browns Valley	Mar. 19	29	2 v.	9	7.6	276	152	290	0	524	118	0.350	0.024	0.000	0.04	15	950	−
Minnesota River above Granite Falls	Mar. 20	29	3 v.+1 m.	<7	4.6	153	193	304	Trace.	428	167	.440	.158	Trace.	.08	10	1,900	−
Minnesota River below Granite Falls	do	29	3 v.+1 m.	<7	4.6	153	192	304	Trace.	429	138	.440	.158	Trace.	.08	7	3,800	+
Minnesota River above New Ulm	Mar. 21	.....	2 v.+2 e.	30	4.6	173	192	275	Trace.	429	131	.280	.172	.01	.11	.....	5,200	−
Minnesota River above Mankato	Mar. 22	81	3 v.+2 e.	150	3.6	173	159	230	0.5	442	107	.490	.180	.03	.32	.....	8,500	+
Minnesota River below Mankato	do	40	2 M.+2 e.	350	3.3	76	121	157	0.5	603	55	.710	.240	.05	.75	.....	40,000	+
Minnesota River just above mouth	Mar. 14	74	2 v.+1 M.	95	3.0	106	138	197	Trace.	364	74	.440	.326	.005	.24	9	4,500	−
Tributaries:																		
Redwood River above Redwood Falls	Mar. 21	.....	3 M.	<7	0.4	46	51	124	Trace.	153	39	.370	.260	.004	.31	5	1,100	−
Redwood River below Redwood Falls	do	.....	3 M.	20	4.0	334	114	382	Trace.	643	172	.412	.146	.002	.31	11	1,700	−
Blue Earth River at mouth	Mar. 22	114	2 v.+2 e.	350	3.6	59	113	130	0.5	844	37	.600	.204	.05	.75	.....	30,000	+

[a] Chemical analyses by H. C. Carel; bacteriological examinations by Dr. E. H. Beckman.
[b] Overgrown.
[c] Chemical analyses by R. B. Dole; bacteriological examination by E. H. Beckman.

TABLE 38.—*Mineral analyses of water in Minnesota River basin.*

[Parts per million.]

Source.	Date.	Oxide of iron and alumina (Al_2O_3+ Fe_2O_3).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Potassium (K).	Silica (SiO_2).	Chlorine (Cl).	Sulphate radicle (SO_4).	Carbonate radicle (CO_3).	Total solids.
Bigstone Lake at Ortonville[a]	1883.	1.5	44	48	37	5.6	106	9.2	220	112	553
Minnesota River at Granite Falls[b]	July -, 1891	5.0	92	19	43		.....	3.8	212	108	484
Chippewa River at Montevideo[b]	Jan. 17, 1891	28	223	66	28		.....	4.1	122	305	676
Chippewa River at Montevideo[b]	Nov. 17, 1895	8.6	88	53	51		.....	17	234	234	582
Chippewa River at Montevideo[b]	Jan. 24, 1902	.....	122	71	39		.....	13	163	295	704
Pomme de Terre River at Appleton[b]	Jan. 11, 1891	11	130	56	40		.....	2.7	258	221	719
Pomme de Terre River at Appleton[b]	Dec. 24, 1901	.....	100	70	26		.....	5.5	219	214	634
Redwood River at Florence[c]	Aug. 21, 1903	1.5	65	16	26	10		9.1	100	102	([d])
Redwood River at Marshall[c]	.....do.....	2.0	92	32	11	18		12	140	134	([e])
Lake at Alden[c]	Oct. 27, 1892	4.4	32	19	22		.....	23	6.5	99	208
Prior Lake at Prior Lake[c]	Nov. 15, 1888	4.1	32	9.9	1.0		.....	1.4	Trace.	71	119
Temperance Lake at Sherburne[c]	Oct. 12, 1892	9.9	34	22	20		.....	3.1	27	113	230
George Lake at Fairmont[c]	Mar. 27, 1894	4.4	34	14	6.7		.....	2.7	Trace.	94	156
Budd Lake at Fairmont[c]	June 27, 1898	1.2	27	15	13		.....	4.6	8.7	84	153
Budd Lake at Fairmont[c]	Feb. 6, 1899	1.5	41	21	11		.....	7.5	13	113	208
Budd Lake at Fairmont[c]	Sept. 18, 1901	.8	18	17	7.2		.....	4.6	9.1	68	124
Sulphur Creek at Ortonville[c]	Sept. 3, 1888	8.6	256	61	110		.....	3.8	700	237	1,377

[a] Analysis by C. T. Sidener; trace of phosphates.
[b] Analyses furnished by Chicago, Milwaukee and St. Paul Railway.
[c] Analyses furnished by Kennicott Water Softener Company.
[d] Suspended solids, 5.0.
[e] Suspended solids, 63.

TABLE 39.—*Analyses of waters of Minnesota and Blue Earth rivers.*

[Parts per million.]

MINNESOTA RIVER ABOVE MOUTH OF BLUE EARTH RIVER.

Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Total alkalinity.	Total hardness.	Iron as Fe.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Free CO_2.	Bacteria per c. c.[a]	B. coli communis.[a]
Aug. 27, 1903[b]	0	0	.....	3	.....	200	170	0	520	.....	0.7	Trace.	Trace.	Trace.	.....	650	—
Jan. 7, 1904[c]	.....	.....	.....	4.2	.....	.....	620	.....	.....	.....	.33	.30	Distinct.	Trace.	.....	10,500	+
May 3, 1904[c]	.....	.....	.....	1.0	.....	.....	.....	.....	.....	.....	.....	.....	.000	Trace.	.....	1,100	+
Dec. 4, 1904[d]	18	2 v.	19	4.5	207	322	529	1.0	619	172	.380	.070	.000	.04	13	300	-
Jan. 4, 1905[d]	25	3 v.	15	4.5	207	380	640	1.0	728	184	.100	.220	Trace.	.09	18	400	-
Mar. 22, 1905[d]	81	3 v.	150	3.6	173	150	230	0.5	442	107	.490	.180	.03	.32		8,500	+

Aug. 27, 1905 [c]																2,500	—
Jan. 7, 1905 [c]				4.8			606				0.35	0.308	Distinct.	Distinct.		([e])	+
May 3, 1904 [c]											.50	.31	.000	Trace.		2,500	+
Dec. 8, 1904 [d]	18		20	4.7	207	330	473	1.0	618	222	.400	.296	.000	.04	18	4,100	+
Jan. 4, 1905 [d]																4,200	+
Mar. 22, 1905 [d]	40	2 M+2 e.	350	3.3	76	121	157	0.5	603	55	.710	.240	.05	.75		40,000	+

BLUE EARTH RIVER AT MOUTH, MANKATO, MINN.

Aug. 27, 1903 [b]				2.5			315	0			0.52	0.047	0	0		2,000	—
Jan. 7, 1904 [c]							408				.18	.308	Distinct.	Distinct.		([e])	+
May 3, 1904 [c]											.55	.41	.000	Trace.		1,200	—
Jan. 4, 1905 [d]	4	1 v.	<7	3.5	71	311	473	Trace.	457	92	.352	.420	.000	.02	20	400	—
Mar. 22, 1905 [d]	114	2 v.+2 e.	350	3.6	59	113	130	0.5	844	37	.600	.204	.05	.75		30,500	+

MINNESOTA RIVER AT MOUTH, FORT SNELLING, MINN.

June 6, 1904 [c]											0.32	0.30	0.000	Trace.		3,900	+
Oct. 23, 1904 [d]	40	1 v.+1 M.	80	8.5		244	243	Trace.	411	107	.502	.130	Trace.	.03		1,800	+
Mar. 14, 1905 [d]	74	2 v.+1 M.	95	3.0	106	138	197	Trace.	364	74	.440	.326	.005	.24	9	4,500	—
June 12, 1905 [d]	81	2 e.+2 v.	55	4.3	123	236		Trace.	473		.40	.054	Trace.	.04		10,000	+

[a] Bacteriological examination by Dr. E. H. Beckman.
[b] Chemical analysis by E. H. Beckman.
[c] Chemical analysis by H. C. Carel.
[d] Chemical analysis by R. B. Dole.
[e] Overgrown.

From Table 39, giving analyses made of water of Minnesota an Blue Earth rivers at Mankato and Fort Snelling, an idea may be ha of the variation in the quality of the water between winter and sum mer. The inorganic substances are higher during the season whe the river is frozen and are supplied mainly by its underground flow In the spring the water exhibits at once its highest color and turbidity and its lowest mineral content. Bacteriological examinations of sam ples taken at Mankato prove the frequent presence of *B. coli com munis* in Minnesota River above the mouth of Blue Earth River, both in summer and in winter. This is probably due to the fact that New Ulm, a short distance above Mankato, discharges its sewage and the effluent from four large breweries into the river. Fig. 4 is a graphic representation of daily turbidity determinations made at Mankato below the mouth of Blue Earth River, extending over a period of seventeen months. The gage heights at the same point are also given for comparison. These curves show an almost exact coincidence between the rise and fall of turbidity and gage height. Ordinarily the river carries suspended matter equivalent to 10 to 40 parts per million of turbidity, but during the spring freshets this amount is often increased to 600 or 800 parts per million.

It is evident that the water of Minnesota River without filtration is not safe for municipal supply. Its purification, however, would not be very difficult, and the water is more desirable for general use than that obtained from deep wells, on account of its comparative softness. The following table shows the average of 24 analyses of Minnesota River, together with the maximum and minimum observations:

TABLE 40.—*Summary of quality of water of Minnesota River.*

[Parts per million.]

Determination.	Maximum.	Minimum.	Average.
Color	81	0	30
Odor			
Turbidity	350	<7	[illegible]
Chlorine	17.5	1.0	6.1
Sulphate radicle	383	76	175
Alkalinity	380	105	220
Total hardness	994	157	470
Iron	1.0	Trace.	Trace.
Total residue	933	364	558
Soluble residue	365	55	165
Free ammonia	.326	.024	[illegible]
Albuminoid ammonia	.710	.100	[illegible]
Nitrates	.75	.025	[illegible]
Nitrites	.05	Trace.	[illegible]

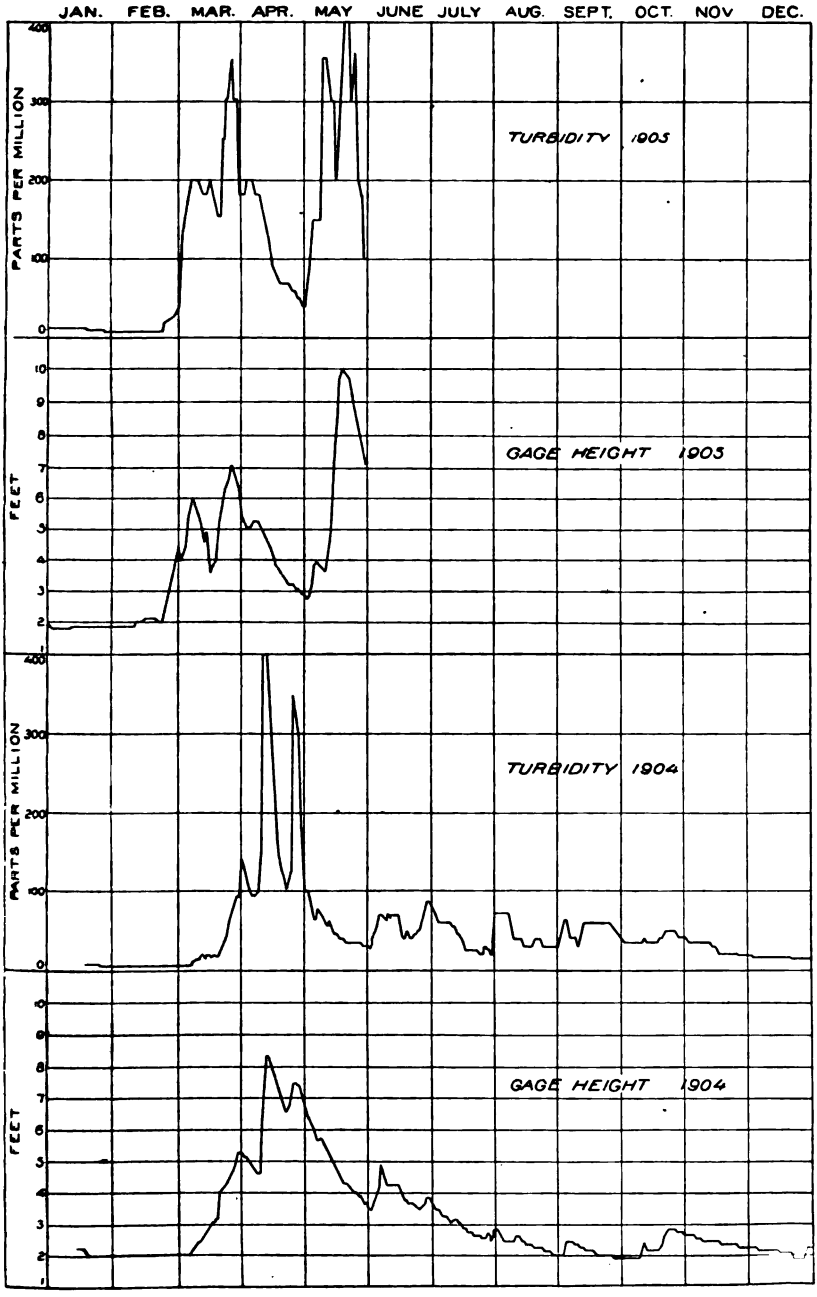


FIG. 4.—Diagram showing relation of turbidity to gage height on Minnesota River at Mankato.

NOTES ON MUNICIPALITIES.

Forty-four of the fifty-two settlements described below have underground water supplies, while only two report stream or lake water as their supply. Sixteen towns, less than one-third, report the installation of sanitary sewage systems. One city reports that a sewage-disposal plant is in operation. Privies and cesspools are common in all of these places, even where sewers have been constructed.

Alden, Faribault County.—On a small creek that enters Walnut Lake. Walnut Lake drains to the east fork of Blue Earth River. The village water supply is derived from a deep well. No sewerage.

Appleton, Swift County.—On Pomme de Terre River, 3 miles above its entrance into Minnesota River. Water supply ordinarily taken from a well, but there is also connection with Pomme de Terre River for use in emergencies. Ice supply from Pomme de Terre River above the village. No sewerage. Garbage is hauled to a dumping ground outside the village.

Belle Plaine, Scott County.—On Minnesota River 52 miles above its mouth. Water supply is obtained from a well in the center of the town, ice supply from small lakes near the borough. No sewerage. Garbage is hauled away to the dumping ground.

Benson, Swift County.—On Chippewa River 40 miles above its confluence with Minnesota River. Water supply is taken from two wells in the village, ice supply from Chippewa River above village. A combined sewerage system discharges into Chippewa River. Garbage is dumped on the prairie 2 miles east of the village.

Bird Island, Renville County.—Drained by a county ditch to Minnesota River. Water supply is derived from an 8-inch tubular well 285 feet deep. No sewerage. No systematic garbage disposal.

Blue Earth, Faribault County.—On Blue Earth River, 20 miles above Winnebago City. Water supply is obtained from two wells, one 6 inches by 375 feet, supplied from the St. Peter sandstone, the other 8 inches by 672 feet, drawing from the "Jordan" sandstone. Ice supply is cut from Browns Lake and from Blue Earth River. Sanitary sewerage, discharging into Blue Earth River, is installed. Garbage is hauled to the public dumping ground.

Browns Valley, Traverse County.—On the low divide between Lakes Traverse and Big Stone. Drainage goes to Big Stone Lake. Water supply is obtained from springs on the east side of the bluffs; ice supply from Lake Traverse. No sewerage. Garbage is hauled out of town and dumped at several points.

Canby, Yellow Medicine County.—On Canby Creek 46 miles above the mouth of Lac qui Parle River. Has a public water service for fire protection only. Ice supply is cut from Canby Creek east of the city. No sewerage. Garbage is taken to the city dumping ground and burned.

Chaska, Carver County.—On Chaska Creek at its entrance into Minnesota River. Water supply, used chiefly for fire protection, is obtained from an 8-inch artesian well 640 feet deep; ice supply from Minnesota River above the city. No sewerage. Garbage is hauled out of town.

Elmore, Faribault County.—Drains to Blue Earth River. Water supply is obtained from a 6-inch drilled well 300 feet deep; ice supply from a small lake and from the river. No sewerage. Garbage is hauled one-half mile out of town to a dumping ground.

Fairmont, Martin County.—Lakes George and Sisseton, which drain by Center Creek to Blue Earth River, receive the surface drainage of the city. Water supply is taken from Lake Budd, a short distance south of the city; ice supply from Lakes George and Budd. No sewerage. Garbage is hauled to the city dumping ground.

Glenwood, Pope County.—On north shore of Lake Minnewaska, from which the ice supply is taken. Water supply is obtained from springs, which flow into a large concrete basin properly protected against pollution. A sanitary sewerage system, equipped with a septic tank, is installed, discharging its effluent into the lake. Garbage is commonly dumped on low ground and covered with earth.

Granite Falls, Yellow Medicine County.—On Minnesota River 16 miles below the mouth of Chippewa River. The only considerable water power on the stream is located at this point. Water supply is taken from Minnesota River. The water goes by a canal from above the dam to the waterworks plant, where it is passed through a bed of coarse gravel and sand into a well. Since the well is at the base of a high gravel bluff there is probably a large ground flow to the well. Ice supply is cut from Minnesota River above the dam. No sewerage. Garbage is hauled to a dumping ground outside the city limits.

Henderson, Sibley County.—On Minnesota River 73 miles above its mouth. Ice supply is taken from a small lake near the city. No systematic garbage disposal. No report on waterworks or sewerage.

Janesville, Waseca County.—At south end and near the outlet of Lake Elysian, which drains by Lesueur River into Blue Earth River. Water supply is obtained from a 3-inch tubular well 75 feet deep. It passes through 61 feet of clay into sand and gravel. No sewerage. Ice supply is cut from Lake Elysian 2 miles above its outlet. There is no public garbage disposal, but each resident takes care of his own household waste.

Jordan, Scott County.—On Sand Creek, about 7 miles above its entrance into Minnesota River. Ice supply is cut from Sand Creek above the dam. Garbage is hauled to the village dumping ground. No report on waterworks or sewerage.

Lake Benton, Lincoln County.—At south end of Lake Benton on the divide. Water supply is procured from a well; ice supply from

Lake Benton, northeast of town. No sewerage. Garbage is hauled outside the village to the regular dumping ground.

Lake Crystal, Blue Earth County.—On shore of Crystal Lake. Water supply, for fire purposes only, is obtained from an 8-inch well, 775 feet deep, drawing water from the rock. Ice supply is cut from Crystal Lake. No sewerage. Garbage is removed to the village dumping ground and covered with earth.

Le Sueur, Lesueur County.—On Minnesota River, 82 miles above its mouth. Water supply is obtained from one 8-inch well, 668 feet deep in the rock; ice supply from Minnesota River. Sanitary sewerage discharges into Minnesota River. Garbage is hauled to the village dumping ground and burned.

Madelia, Watonwan County.—Near Watonwan River, just below the junction of North and South forks. Water supply is procured from two 6-inch wells, each 206 feet deep; ice supply from three lakes near the village. Sanitary sewerage discharges into Watonwan River. Garbage is hauled to a dumping ground near Watonwan River.

Madison, Lac qui Parle County.—Five miles from Lac qui Parle River. Water supply, for fire protection only, is derived from cisterns in the city. Ice supply is cut from Lac qui Parle River and some small lakes. No sewerage. Garbage is removed to the city dumping ground, where it is sometimes burned.

Mankato, Blue Earth County.—On Minnesota River, just below the entrance of Blue Earth River. Water supply is obtained from two artesian wells, 650 feet deep in the rock. Ice supply is cut from Minnesota River, above the city. Sanitary and storm sewerage discharges into Minnesota River. Garbage is commonly hauled outside the city limits and dumped. The Second State Normal School and St. Joseph's Hospital are situated in this city.

Mapleton, Blue Earth County.—Drainage to Blue Earth River by way of Little Cobb Branch and Lesueur River. Water supply is obtained from a deep well. A combined system of sewerage discharges into Little Cobb River. Ice supply is cut from an artificial lake supplied by wells. Garbage is hauled to the village dumping ground.

Marshall, Lyon County.—On Redwood River, 45 miles above its mouth. Water supply is procured from an artesian well, 410 feet deep in the rock, and a dug well, 40 feet deep by 12 feet in diameter, with two driven pipes in the bottom, 4 inches by 70 feet and 9 inches by 90 feet, respectively. An 8-inch well, 250 feet deep, is used for the boiler supply and there is also an emergency pipe to Redwood River. Ice supply is cut from Redwood River on the outskirts of the village. A sanitary and storm sewerage system discharges into Redwood River. Garbage is hauled outside the city.

Milbank, Grant County, S. Dak.—On Whetstone River, 12 miles above its entrance into Minnesota River. Water supply is obtained from deep wells in the town; ice supply from Whetstone River above the city. A combined system of sewerage is in process of construction. Garbage is hauled outside the city and burned or covered with dirt.

Minneota, Lyon County.—On south branch of Yellow Medicine River. Water supply is obtained from a 6-inch tubular well, 105 feet deep, drawing from the sandstone; ice supply from Yellow Medicine River. A combined sewerage system discharges into the river. Garbage is collected and burned regularly, except during the winter.

Montevideo, Chippewa County.—On Chippewa River, 1 mile above its entrance into Minnesota River. Water supply is taken from collecting galleries sunk in an uninhabited gully 3 miles north of town; ice supply from Chippewa and Minnesota rivers. A combined sewerage system discharges into Chippewa River. Garbage is hauled to the village dumping ground.

Montgomery, Lesueur County.—Drained by a county ditch to a neighboring lake, which connects with Minnesota River. Water supply is procured from a 10-inch well 238 feet deep; ice supply from Lake Pepin, north of the city. No sewerage. No systematic garbage disposal.

Morris, Stevens County.—Drained to Pomme de Terre River, 2 miles east of town. Water supply is taken from five 8-inch wells 78 feet deep, one mile east of the city; ice supply from Pomme de Terre River. No sewerage. A United States Indian School situated near the city is supplied with city water and discharges its sewage into the river after it has passed through a septic tank. Garbage is hauled to dumping grounds outside the city limits.

Morton, Renville County.—On Minnesota River about 6 miles below the entrance of Redwood River. Water supply is procured from springs in a gravel bluff above the village level; ice supply from Minnesota River. No sewerage. Garbage is removed to a dumping ground outside the village limits.

Mountain Lake, Cottonwood County.—Between the North and South forks of Watonwan River. Water supply is obtained from a well in the village, 10 feet deep, provided with a stone curbing. Ice supply is cut from a creek near the village. No sewerage. Garbage is removed to the public dumping grounds.

New Prague, Scott and Lesueur counties.—Water supply is procured from an 8-inch well 300 feet deep; ice supply from an artificial lake in the city. No sewerage. No systematic garbage disposal.

New Ulm, Brown County.—On Minnesota River, 22 miles above Mankato. Water supply is obtained from wells in the city, about 200 feet deep, two with 6-inch, three with 8-inch, and one with 10-inch casing.

They are said to go through 145 feet of clay and 20 feet of sandstone to granite. Ice supply is cut from Minnesota River. A combined sewerage system discharges into Minnesota River. Garbage is hauled to the city dumping ground and buried.

Olivia, Renville County.—Drains to Minnesota River by way of the east fork of Beaver Creek. Ice is commonly not cut in the vicinity, but is shipped in from Granite Falls. Garbage is hauled into the country. No report on waterworks or sewerage.

Ortonville, Bigstone County.—At the foot of Big Stone Lake on Minnesota River. Water supply is procured from a dug well, 45 feet deep by 26 feet in diameter; ice supply from Big Stone Lake, 1 mile from the city. No sewerage. There is no systematic garbage disposal.

Ottawa, Lesueur County.—On Minnesota River, 90 miles above its mouth. No waterworks or sewerage. Ice supply is cut from Minnesota River.

Redwood Falls, Redwood County.—On Redwood River, just above its entrance into Minnesota River. Water supply is obtained from a dug well in the outskirts of the village, 12 feet in diameter by 20 feet in depth. There is also a connection with Redwood River for use in emergencies. Ice supply is cut from Redwood River above the dam. A sanitary sewerage system discharges into Redwood River below the dam.

Renville, Renville County.—Connected with Minnesota River by Sacred Heart Creek. Water supply is obtained from an 8-inch well, 230 feet deep, passing through about 180 feet of clay into water-bearing sand. Ice supply is obtained from Granite Falls. No sewerage. Garbage is removed to the village dumping grounds.

St. James, Watonwan County.—Drains to Watonwan River by St. James Creek. Water supply is obtained from one well 8 inches by 185 feet; one well 10 inches by 385 feet, for domestic use; and one dug well 40 feet deep, for boiler use. Ice supply is cut from St. James Lake, west of the city. A sanitary sewerage system discharges into St. James Creek. Garbage is hauled to the dumping grounds below the city.

St. Peter, Nicollet County.—On Minnesota River, 97 miles above its mouth. Water supply is obtained from an 8-inch well 350 feet deep; ice supply from a small lake at the foot of the bluffs. A storm sewerage system discharges into Minnesota River. Garbage is commonly hauled to the city dumping ground. Gustavus Adolphus College, with about 350 students, and the First State Hospital for the Insane, with 1,000 to 1,200 inmates, are located at this place. The water supply for the hospital is procured from two 6-inch wells, 260 feet deep, in water-bearing sandstone. A sanitary sewerage system from the hospital empties into Minnesota River.

Shakopee, Scott County.—On Minnesota River, 26 miles above its mouth. No waterworks or sewerage. Ice supply is cut from Minnesota River. Garbage is hauled to the village dumping ground.

Sherburne, Martin County.—Near Temperance Lake. Water supply is obtained from an artesian well; ice supply from Fox Lake, 2 miles north of Sherburne. Sewerage not reported. Garbage is removed to the city dumping ground.

Sleepy Eye, Brown County.—Drains to Big Cottonwood River by way of Sleepy Eye Creek. Water supply is procured from a dug well in the center of town, 20 feet in diameter and about 20 feet deep. In the bottom of this pit a casing is driven to rock. Ice supply is cut from Sleepy Eye Lake and Cottonwood River. No sanitary sewerage. Garbage is regularly removed to the city dumping ground.

Springfield, Brown County.—On Big Cottonwood River. Water supply, for fire protection and sprinkling only, is obtained from a 6-inch well 28 feet deep, in the village. Ice supply is cut from Big Cottonwood River above the dam. No sewerage. Garbage is occasionally hauled outside the village.

Tracy, Monroe Township, Lyon County.—Water supply is obtained from a 10-inch drilled well, 500 feet deep; ice supply from Lake Sigel. No sewerage. Garbage is hauled to the village dumping ground.

Waconia, Carver County.—On south shore of Clearwater (Waconia) Lake. No public water supply. Ice supply is cut from Clearwater Lake. Storm sewerage has been installed, but no sanitary system. Garbage is hauled to the village dumping ground.

Waseca, Waseca County.—A short distance from Clear Lake. Water supply is procured from two artesian wells, 10 inches by 400 feet and 10 inches by 1,000 feet, respectively. Ice supply is cut from Clear Lake. No sewerage. No regular garbage disposal.

Wells, Clark Township, Faribault County.—Water supply is obtained from a 12-inch artesian well and an 8-inch well, 200 feet deep. Ice supply is cut from an artificial lake, which is filled with water from the public supply. A combined sewerage system is installed, the outlet of which is not reported.

Westbrook, Cottonwood County.—Near Double Lake, which discharges into Cottonwood River. The village is equipped with water service for fire protection only. No sewerage.

Willmar, Kandiyohi County.—Near Foot Lake, which discharges by way of Hawk Creek into Minnesota River. Water supply is obtained from wells 240 feet deep; ice supply from Eagle Lake, 5 miles northeast of the city. The city has storm and sanitary sewerage.[a]

Winnebago, Faribault County.—One and one-half miles east of Blue Earth River. Water supply is obtained from an 8-inch well, 283 feet

[a] Baker, M. N., Manual American Waterworks, 1897, p. 454.

deep, ice supply from Blue Earth River. No sewerage. Garbage is hauled to the village dumping ground.

Winthrop, Sibley County.—Near the North Branch of Rush River to which its surface drainage goes. Water supply is procured from a 10-inch drilled well, 239 feet deep, which passes through about 20 feet of blue clay into water-bearing gravel and sand. Ice supply is cut from Sand Lake, 3 miles from the village. No sewerage. Garbage is hauled to a dumping ground 2 miles from the village.

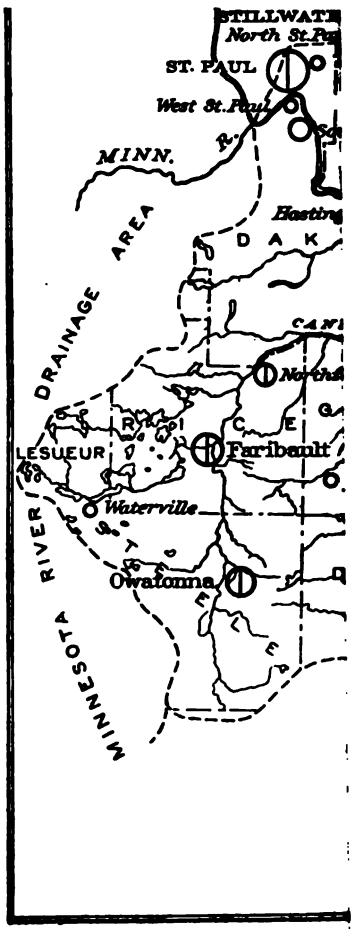
ST. CROIX RIVER BASIN.

GENERAL DESCRIPTION.

Boundaries.—The St. Croix basin is bounded on the east by Chippewa River drainage area, on the west by upper Mississippi River drainage area, and on the north by drainage areas of streams tributary to Lake Superior. It forms part of the boundary between Minnesota and Wisconsin. (Pl. IV.)

Character and slope of St. Croix River.—St. Croix River has its head in Upper St. Croix Lake, a body of water in Township 45 N., R 11 W., Douglas County, Wis., about 25 miles east of the Minnesota-Wisconsin boundary. This lake, which is 4 miles long and one-half mile wide, is fed by many springs from its sandy bed and along its banks. After emerging from this lake, the river flows generally southwestward for 70 miles to the mouth of Kettle River, and thence pursues a more southerly direction to its confluence with the Mississippi. Its watershed comprises many forests of pine and hard wood, dotted by cedar or tamarack swamps. The major part of the territory was formerly covered with timber, but steady encroachments have been made upon it from the south until much of it has been converted into farms. The river is navigable for light-draft vessels from its mouth to The Dalles of the St. Croix at Taylors Falls. At St. Croix Boom, one mile above Stillwater, the river spreads out to form a lake one-half mile to 1 mile wide, which continues to Prescott. This sheet of water, 25 miles long and 6 to 15 feet deep, has a barely perceptible current, except during flood times. At its lower end it narrows abruptly to a channel about 100 feet wide, which connects with Mississippi River 3 miles below Hastings. St. Croix River flows for the most part between high bluffs of gravel or of rock. It is extensively used for logging purposes. Numerous lakes lie within its drainage area, especially in the upper part of the valley, though none of them are of large size.

In the first 20 miles of its course, including Upper St. Croix Lake, the river falls but little. (Pl. V.) It then enters upon a series of



MAP OF ST. CROIX

rapids which extend to the mouth of Yellow River, 28 miles, and in which the average slope is 4.2 feet per mile. The stream then continues with a slope of 1.6 feet per mile to the head of Kettle River Rapids. A section of rapid descent extends thence to the head of navigation at Taylors Falls, in which the river falls about 3.5 feet per mile. Below this point the grade is slight, so that from Stillwater to Prescott there is hardly any fall at all. In the last 50 miles of the river's course, the navigable portion, there is a grade of 0.3 foot per mile. The principal falls are Kettle River Rapids, at the mouth of Kettle River, and St. Croix Falls, just above Taylors Falls village. In the 170 miles from the mouth of the river to the head of Upper St. Croix Lake there is a total fall of 345 feet, or an average of 2 feet per mile.

Tributaries of St. Croix River.—Many short streams enter St. Croix River. (See Pl. IV.) Kettle River, its largest tributary, rises in Township 49 N., R. 14 W., Carlton County, Minn., and flows in a southerly direction across the open, sandy lands of Carlton and Pine counties to its entrance into St. Croix River. It has several falls, especially in its lower course, where it drops 185 feet in 25 miles. Namekagon River, the tributary second in size, is the outlet of Namekagon Lake, which is located in the central part of Buffalo County, Wis. The river flows southwestward, then westward, entering St. Croix River 133 miles above its mouth. It is a forest stream, much used for logging purposes. The following list gives the chief tributaries of St. Croix River, with the area drained by each and the distance from its mouth to Prescott:

TABLE 41.—*Principal tributaries of St. Croix River.*

Tributary.	Drainage area.[a]	Distance of mouth above Prescott.
	Sq. miles.	*Miles.*
Apple	427	30
Clam	416	108
Kettle	1,093	95
Namekagon	1,025	133
Snake	937	92
Yellow	310	122

[a] Water powers of the United States, Tenth Census U. S., pt. 2, sec. 2, p. 77.

Geology.—The formations which, in other sections of the State, especially in its western half, make drainage water hard or alkaline are absent from St. Croix Valley. Drift generally covers the area to a depth of 75 to 100 feet, except in the deeper valleys, so that outcrops of rock are infrequent and limited in extent. Trap appears in the valleys of Pine County and at Taylors Falls in Chisago County, where precipitous walls of it extend along the river for some distance. In Kanabec County the limited exposures are coarse-grained syenite,

granite, and schist. Sandstone is seen along Kettle River and is fou extensively in the southern part of the main valley. Limesto which underlies most of Washington County, is in sight at St water.[a] Cretaceous formations apparently do not lie in this bas The most important geologic feature from a hydro-economic view the apparent absence of calcareous rocks in the upper part of t valley around the headwaters of the principal streams.

Soil and subsoil.—The transported Pleistocene materials are deriv mainly from areas of early rocks around Lake Superior and we deposited as bowlder clay or till, in which water-bearing beds of sa and gravel are found. There are many areas of stratified gravels a sands of the modified drift. Alluvium similar to that in lower Missi sippi Valley occurs along St. Croix River bottom as far north as Tayl Falls. Throughout Chisago and Isanti counties a yellow gravel a sand subsoil is found and sandy soils occur in many parts of the are The following table gives averages of analyses of soil from differe parts of St. Croix Valley made by the Minnesota Agricultural Exper ment Station:

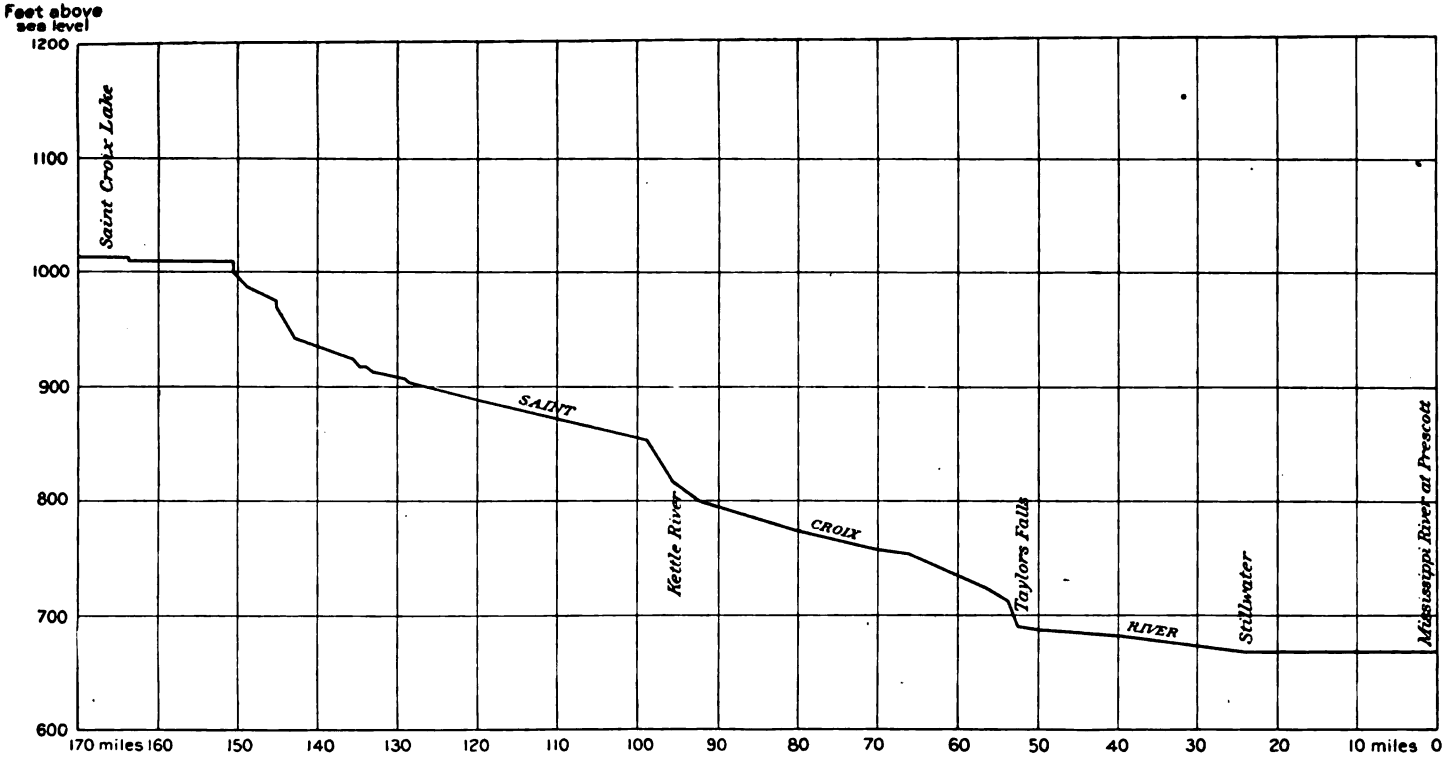
TABLE 42.—*Chemical composition of soil and subsoil in St. Croix River basin.*

	Surface soil.		Subsoil.	
	St. Croix River basin.	Entire State.[a]	St. Croix River basin.	Entire State.[a]
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Insoluble in HCl	86.64	79.92	86.97	[illegible]
Volatile	3.65	8.98	3.91	[illegible]
Potassium oxide (K_2O)	.19	.43	.23	[illegible]
Sodium oxide (Na_2O)	.19	.45	.27	[illegible]
Calcium oxide (CaO)	.48	1.29	.36	[illegible]
Magnesium oxide (MgO)	.28	.61	.32	[illegible]
Oxides of iron and aluminum ($Fe_2O_3 + Al_2O_3$)	5.70	7.20	6.57	[illegible]
Phosphoric anhydride (P_2O_5)	.41	.20	.42	[illegible]
Sulphuric anhydride (SO_3)	.07	.10	.06	[illegible]
Carbonic anhydride (CO_2)	.09	.62	.09	[illegible]

[a] Snyder, H., Characteristic features of Minnesota soils: Bull. 65, Agr. Exp. Sta., University of Minnesota, Chem. Div., Nov., 1899, p. 69.

These averages show characteristics pertaining to sandy soils Siliceous matter is high, while all other constituents are low, both soil and subsoil containing about half as much as the State in general of those ingredients known as incrustants. Calcium, magnesium, and sulphuric and carbonic acids are small in amount and there is little sodium or potassium. As a result of this composition of the upper drift layers the water of St. Croix River is one of the softest in the State.

[a] Minn. Geol. and Nat. Hist. Survey, Final Rept., vol. 2, Geology of Washington, Isanti, Kanabec, Chisago, and Pine counties.



PROFILE OF ST. CROIX RIVER.

Reproduced from Exhibit Q, Lake Superior and Mississippi Canal, H. Doc. 330, Fifty-fourth Congress, first session.

INDUSTRIAL POLLUTION.

Twenty-three[a] establishments in St. Croix basin were reported as likely to furnish wastes of deleterious character.

TABLE 43.—*Industrial establishments causing stream pollution in St. Croix River basin.*

Breweries	5
Gas works	1
Sawmills	13
Starch factories	4

The breweries are small and their effluents are not large in amount.

Lumbering.—Lumbering is still the principal industry, and the industrial pollution from this source is important. Nine large sawmills are located at Stillwater and South Stillwater on Lake St. Croix. The logs are boomed and stored on the lake. After the lumber is sawed much of it is rafted down the river. Doubtless a large amount of the color in St. Croix River is due to dissolved resins and other extractives from the logs floated in the water and from the sawdust, bark, and other kinds of refuse that reach the stream. During the past ten years from 300,000,000 to 350,000,000 feet of logs have been run annually on St. Croix River above Stillwater.[b] The waste from this industry is not, however, specifically dangerous or likely to become noxious during putrefaction. It is undesirable because it increases the color and the organic content of the water and provides foci for the growth of bacteria.

Starch making.—Complaint was made in 1900 that Goose Creek, in Chisago County, was being polluted by a starch factory at Harris.[c] Inspection showed that the stream for 2 or 3 miles below the factory was full of potato gratings in an advanced state of putrefaction, and it was claimed that fish in the creek were killed by the waste. This condition is typical where the effluent from these factories is permitted to enter streams without previous purification. In the usual method for manufacturing starch from potatoes the tubers are first washed free from adhering dirt and sand by agitation in a revolving drum with brushes so placed as to scrub the potatoes. The waste water from this process contains the coloring matter of the skins, some particles of the peelings, and a large amount of dirt. The potatoes are then rasped or ground to a soft pulp, which is passed through a series of shaking sieves or revolving wire-gauze cylinders where the starch is washed out with water. After the suspended starch is removed from this liquid by levigation it still contains the soluble part of the potato, considerable potash, phosphoric acid, albumin, and other

[a] One sawmill in Ellsworth, Wis.; 1 in New Richmond, Wis.; 1 sawmill and 2 breweries in Hudson, Wis., and 1 starch factory in River Falls, Wis., are included in this number.

[b] Ann. Rept. Chief of Engineers, U. S. Army, 1901, p. 2332.

[c] Biennial Rept. State board of health of Minnesota for 1899-1900, p. 111.

nitrogenous matters, which rapidly become offensive by putrefactive fermentation.[a] These waste liquids can be used to irrigate land, while the pulp remaining after the starch is extracted can be pressed and dried for sale as a low-grade cattle food. There is no excuse for discharging this waste into streams, for with a small amount of care valuable materials which now create a nuisance could be economically recovered.

MUNICIPAL POLLUTION.

Population and pollution.—Stillwater and Taylors Falls, on the main stream, are two of the oldest places in the State. Pioneers attracted by the seemingly inexhaustible timber resources of the area built up a vast lumber industry, with its headquarters at Stillwater. Settlers seeking farms followed the lumbermen in their progress northward and are now turning the former forest lands into wheat farms. Up to the present time few large villages have been established in the drainage area, and the population, except the large percentage of it concentrated at Stillwater, is composed of farming communities and of inhabitants of lumber camps. The following table shows the distribution by counties of the total population in St. Croix Valley for three successive censuses. (See also Pl. IV.)

TABLE 44.—*Population in St. Croix River basin.*

County.	U. S. Census, 1890.	U. S. Census, 1900.	State Census, 1905.
Aitkin	200	388	686
Anoka	205	374	440
Bayfield, Wis	407	747	1,900
Burnett, Wis	4,393	7,478	9,261
Carlton	1,096	2,778	13,678
Chisago	10,359	13,248	14,341
Douglas, Wis	272	924	1,220
Isanti	235	372	452
Kanabec	1,579	4,614	6,194
Millelacs	200	300	400
Pierce, Wis	4,928	5,723	5,594
Pine	4,052	11,546	14,869
Polk, Wis	12,968	17,801	20,865
Sawyer, Wis	988	3,157	4,172
St. Croix, Wis	16,857	19,518	19,492
Washburn, Wis	2,761	4,991	2,439
Washington	23,308	24,996	25,908
Total population	84,718	118,955	141,931

TABLE 45.—*Density of population in St. Croix River basin.*

	Drainage area.	Inhabitants per square mile.		
		1890.	1900.	1905.
	Sq. miles.			
Above Stillwater:				
Entire area	[b] 7,000	5.7	9.8	13.0
Excluding chief settlements		5.6	9.6	12.8
Above Mississippi River:				
Entire area	[c] 7,655	11.1	15.5	18.5
Excluding chief settlements		8.4	12.4	15.2

[a] Thorp, F. H., Outlines of Industrial Chemistry, 1901, p. 360.
[b] Measured from best available maps. [c] Gannett, H., Twelfth U. S. Census, Bulletin I.

The number of inhabitants per square mile in the valley is considerably less than the average for the entire State. The distribution of both rural and urban populations is similar to that of the Mississippi area above Minneapolis. In the upper part of the basin the population is scant, only two villages, North Branch and Sandstone, having had more than 1,000 inhabitants in 1900. The lower part is more thickly inhabited and contains several important settlements, the largest of which, Stillwater, with a population of 12,435, is one of the industrial and commercial centers of the State. The growth of 10 per cent in these cities and villages during the last 15 years is small as compared with the rapid increase of villages in other parts of the State. During the same period an increase of 60 per cent in the total population of the area indicates an important occupation of territory by farmers and homesteaders. Within the last decade and a half the number of inhabitants per square mile in the area above Stillwater has more than doubled, and the part of the valley that was developed earlier has shown a decided increase. The population is not yet so dense as that of Minnesota Valley and there is still prospect of growth.

The portion of St. Croix Valley above Stillwater includes over 90 per cent of the basin, but is occupied by a little over 60 per cent of the population. The density of population is considerably less than in the St. Croix Valley as a whole. North Branch and Sandstone are the largest villages. Mora, Taylors Falls, St. Croix, and Pine City are other places of minor importance. None of these towns have sanitary sewerage, and the pollution of St. Croix River by them is not large.

The principal cities and villages of the valley of St. Croix River are situated a short distance above the confluence of this stream with the Mississippi.

TABLE 46.—*Principal settlements in St. Croix River basin.*

Place.	Distance above Mississippi River.	Population.		
		1890.	1900.	1905.
	Miles.			
Hudson, Wis	15	2,885	3,259	3,220
New Richmond, Wis	30	1,408	1,631	1,824
North Branch [a]	79	1,141	1,211	1,375
Prescott, Wis	0	911	1,002	889
River Falls, Wis	12	1,783	2,008	2,300
Sandstone	120	1,054	1,189	1,589
South Stillwater	20	1,453	1,422	1,572
Stillwater	23	12,004	12,318	12,435
Total urban population		22,639	24,040	25,204

[a] Including Branch Township.

Three of the six cities below and including Stillwater, having a population of 17,000, are equipped with sanitary sewerage. The larger two (see Table 46), Stillwater and Hudson, discharge their sewage without purification into the sedimentation basin of the lower river, called Lake St. Croix. It is probable that a great part of the sewage is rendered innocuous before it reaches Mississippi River. While the discharge of raw sewage into this part of the river can not be commended, the volume of pollution from these sources is insignificant when compared with the discharge of sewage into Mississippi River at Minneapolis and St. Paul.

Typhoid fever.—Comparatively few cases of typhoid fever occur in this region, doubtless because it is not thickly settled. Stillwater, the chief commercial center and the largest city in the area, has naturally the most typhoid fever. The use of Lake McKusick as a partial source of supply subjected the city to constant danger, because there was no provision against infection from houses and other buildings on the banks of the lake. Fortunately, no cases of typhoid fever were cared for in that immediate locality while the lake water was used, and this source of domestic supply has now been abandoned.

QUALITY OF WATER.

Two series of samples from St. Croix River were examined.[a] The first was taken in the fall of 1904, while the river was open and at an ordinary stage. The second was collected when the river was covered with ice about 30 inches thick and is fairly representative of winter condition. Examinations of Lake McKusick and Browns Creek at Stillwater were made during the summer and fall of 1904.

TABLE 47.—*Quality of water in St. Croix River basin.*[b]

[Parts per million.]

Locality and source.	Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Total alkalinity.	Total hardness.	Iron.
St. Croix River—									
Above Taylors Falls	Oct. 22, 1904	120	2 v.	35	0.8	0	45	49	0
Below Taylors Falls	do	162	2 v.	30	.8	0	45	49	0
Above Stillwater	Oct. 21, 1904	162	2 v.	17	1.0	0	58	63	0
Below Stillwater	do	148	2 v.	15	1.5	0	58	63	0
Above Prescott	Oct. 14, 1904	29	2 v.	9	.3	0	87	90	0
Above Taylors Falls	Mar. 15, 1905	18	2 v.	10	1.2	Trace.	91	84	1.0
Below Taylors Falls	do	22	2 v.	10	1.4	Trace.	72	67	1.0
Above Stillwater	Mar. 16, 1905	18	2 v.	9	1.4	Trace.	95	90	1.0
Above Prescott	Feb. 11, 1905	25	1 v.	<7	1.1	[c] 5	108	111	Trace.
Lake McKusick at Stillwater, average of five analyses	Aug. 15, 1904	40	3 v.	<7	1.1	.....	139	135	.....
Browns Creek at Stillwater	Oct. 1, 1904	25	2 v.	<7	.7	.....	182	188	.....

[a] See Pl. I for location of sampling stations.
[b] Chemical analyses by R. B. Dole. Bacteriological examinations by Dr. E. H. Beckman.
[c] Estimated.

TABLE 47.—*Quality of water in St. Croix River basin*—Continued.

[Parts per million.]

Locality and source.	Date.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Bacteria per c. c.	B. coli communis.
St. Croix River—									
Above Taylors Falls	Oct. 22, 1904	115	9	0.192	0.098	0.000	0.04	3,500	+
Below Taylors Falls	do	120	10	.192	.092	.000	.04	4,800	+
Above Stillwater	Oct. 21, 1904	127	8	.420	.052	.000	.04	2,400	+
Below Stillwater	do	112	9	.408	.046	.000	.04	1,300	+
Above Prescott	Oct. 14, 1904	118	8	.210	.054	.000	.05	670	+
Above Taylors Falls	Mar. 15, 1905	129	9	.162	.024	.000	.05	750	−
Below Taylors Falls	do	110	10	.402	.180	Trace.	.05	1,100	−
Above Stillwater	Mar. 16, 1905	133	8	.140	.022	.000	.05	400	+
Above Prescott	Feb. 11, 1905	132	7	.194	.014	.000	.10	64	−
Lake McKusick at Stillwater, average of five analyses	Aug. 15, 1904	183	15	.240	.434	.12	.19	1,400	+
Browns Creek at Stillwater	Oct. 1, 1904	208	11	.078	.024	.007	.45	1,700	+

The characteristic effect of woodland drainage is seen in the high albuminoid ammonia, color, and odor. On the other hand the mineral content is low. There is practically no sulphuric acid present and very little chlorine or iron. The turbidity is low for the samples examined, and the amount of suspended matter is never excessive. The low hardening constituents, which are principally bicarbonates of calcium and magnesium, indicate that the stream is excellent for boiler use.

B. coli communis was isolated in pure culture from every sample taken in the fall, while in the winter it was found only above Stillwater. The number of bacteria per cubic centimeter was found to be considerably lower in winter than in fall. It is especially significant that both examinations at Prescott show a diminution in the number of bacteria present. Two other examinations of water from the river at Prescott also gave very small numbers of bacteria; on August 29, 1903, 45 colonies were counted, and on June 8, 1904, there were 130, while *B. coli communis* was not isolated in either case.

The effect of sedimentation is further shown by the reduction in color, odor, turbidity, albuminoid ammonia, and free ammonia, and the increase in nitrates. At the same time there is an increase in alkalinity, hardness, and total residue, probably due to the introduction of ground water from the limestone region along the shores of Lake St. Croix. The same changes were noted between summer and winter conditions as in other streams; the nitrogens, color, and bacterial content decrease, while all amounts representing mineral matter are increased, showing the effect of a change in the percentage of underground flow to the river. The principal features to be noted in regard to the quality of this water are that it drains from a wooded, swamp, and farming country, not very thickly settled; that there are no serious industrial pollutions in the area; that it is softer than

that of the other two great tributaries of Mississippi River in Minnesota; that the small amount of municipal pollution is largely eliminated by sedimentation and oxidation in Lake St. Croix.

In conclusion a table is given showing the average of nine analyses of the river water, with the maximum and minimum determinations. The water is likely to vary considerably from these figures because they do not represent examinations made over a long period.

TABLE 48.—*Summary of quality of water of St. Croix River.*

[Parts per million.]

Determination.	Maximum.	Minimum.	Average.
Color	162	18	70
Odor	2 v.	1 v.	2 v.
Turbidity	35	<7	14
Chlorine	1.5	0.3	1.0
Sulphate radicle	[a] 5	0	Trace.
Alkalinity	108	45	89
Total hardness	111	49	89
Iron	1.0	0	Trace.
Total residue	133	110	135
Soluble residue	10	7	9
Free ammonia	.180	.014	.094
Albuminoid ammonia	.420	.140	.239
Nitrates	.10	.04	.05
Nitrites	Trace.	.000	.000

[a] Estimated.

NOTES ON MUNICIPALITIES.

Of the 8 Minnesota settlements mentioned below wells are reported as public water supplies from 5. Sanitary sewerage has been installed at only one place.

Hudson, St. Croix County, Wisconsin.—On St. Croix River at the mouth of Willow River. Water supply is taken from two 8-inch artesian wells, 250 and 500 feet deep, respectively, which enter sandstone at 15 feet and are supplied from it. Ice supply is procured from Willow River and from St. Croix River, which is at this point known as Lake St. Croix. A sanitary sewerage system discharges into St. Croix River.

Mora, Kanabec County.—On Snake River 30 miles above St. Croix River. Water supply is procured from one 10-inch driven well, 210 feet deep; ice supply from Lake Mora. No sewerage. Garbage is hauled to the public dumping ground.

New Richmond, St. Croix County, Wisconsin.—On Willow River 1 miles above its mouth. Water supply is obtained from a 6-inch well drilled 185 feet deep; ice supply from Willow River above the dam. A combined sanitary and storm sewerage discharges into Willow River. Garbage is hauled to the village dump.

North Branch, Chisago County.—On North Branch River 8 miles above St. Croix River. No waterworks, sewerage, or public garbage disposal. Ice supply is cut from two small lakes near the village.

Pine City, Pine County.—On Snake River at the outlet of Cross Lake. No waterworks or sewerage. Ice supply is cut from Snake River. Garbage is buried or burned at the village dumping ground. A private sanitarium for the treatment of tuberculosis is situated above the town.

Prescott, Pierce County, Wisconsin.—At confluence of St. Croix and Mississippi rivers. No waterworks or sewerage. Ice supply is cut from Lake St. Croix. Garbage is carted outside the village limits and burned.

River Falls, St. Croix and Pierce counties, Wisconsin.—On Kinnickinnic River, 12 miles above Prescott. Water supply is obtained from artesian wells 550 feet deep. There is no public sewerage. Ice supply is cut from the mill pond on Kinnickinnic River. Garbage is hauled outside the city limits.

Rush City, Chisago County.—On Rush Creek. Water supply, for fire protection only, is obtained from shallow wells. Ice supply is cut from Rush Lake. No sewerage. Garbage is hauled outside the village limits.

Sandstone, Pine County.—On Kettle River, about 25 miles above St. Croix River. Water supply is derived from two wells drilled in sandstone, 12 inches by 750 feet and 10 inches by 150 feet, respectively. Ice supply is cut from Miller and Wolf lakes. No sewerage. Garbage is hauled to the village dumping ground, where all putrescible matter is burned.

South Stillwater. Washington County.—On St. Croix River, 20 miles above its mouth. Water supply, for fire protection only, is procured from a dug well 25 feet deep by 20 feet diameter, on the bank of a brook, with which there is also an emergency connection. Ice supply is cut from St. Croix River. No sewerage. Garbage is hauled to the public dumping grounds.

Stillwater, Washington County.—On St. Croix River 23 miles above its confluence with Mississippi River. Has two distinct water systems. One, for drinking and domestic use only, is supplied by a spring in the sand rock and a deep well, both located in the central part of the city. The deep well, drilled 2,640 feet deep and 8 inches in diameter, was cased 650 feet and afterward plugged at 750 feet,[a] so that the water is probably derived from the "Potsdam" sandstone. The other water system, for fire protection and boiler use, is supplied by Lake McKusick, a small shallow body of water on the outskirts of the city. The ice supply is taken from Lily Lake, within the city limits, and from St. Croix River in front of the city. The sewerage discharges by two main outlets into St. Croix River near the bridge. The Minnesota State prison is situated near St. Croix River, in the

[a] The Stillwater deep well; review of paper by A. D. Meeds, read before the Minnesota Academy of Natural Sciences: Am. Geol., vol. 3, 1889, p. 342; Science, vol. 13, No. 329, p. 401.

northern part of Stillwater. Its sewage is discharged into St. Croix River.

Taylors Falls, Chisago County.—On St. Croix River 52 miles above its mouth. No waterworks or sewerage. Ice supply is cut from Thaxter Lake, Wisconsin. Garbage is commonly hauled outside the village limits.

MISSISSIPPI RIVER BASIN BETWEEN MINNESOTA RIVER AND THE IOWA LINE.

GENERAL DESCRIPTION.

Area discussed.—Above the southern border of Minnesota the Mississippi River basin extends over nearly one-half of Minnesota and Wisconsin, including the area drained by Minnesota, St. Croix, Chippewa, and Black rivers. The area considered under this heading includes the portions of Minnesota that are drained by Mississippi River below Minnesota River except the St. Croix basin (Pl. IV), which is described under a separate heading. Examinations of the main stream were, however, made only as far south as the foot of Lake Pepin, just above the entrance of Chippewa River, near Wabasha, Minn. Consequently, the discussion of the quality of water in this lower section is confined to that part of the basin that lies above the mouth of Chippewa River. The consideration of municipal pollution above that point must necessarily have reference to settlements on the upper portion of the Mississippi, on the Minnesota, and on the St. Croix. In addition there is presented a brief summary of conditions in settlements of the Minnesota portion of the area.

Character and slope of Mississippi River.—After passing Minneapolis, the Mississippi assumes the appearance that characterizes its lower sections. From a swift running, highly colored stream it becomes sluggish, receives considerable suspended matter from its tributaries, and spreads out over a wide alluvial bottom cut by sloughs and dotted with islands. Its slope is greatest from St. Anthony Falls to the mouth of Minnesota River, a stretch in which the stream passes through a deep, wide gorge which it has excavated during the gradual recession of the falls. After it is joined by Minnesota River it commences to occupy a broad valley, through which it runs in a tortuous course. St. Croix River enters from the north 32 miles below Minnesota River. The Mississippi then pursues a southeasterly course to the State border. Its valley is from 2 to 3 miles wide and 50 to 200 feet deep, with sandstone and lime rock frequently exposed along its banks. The river follows several channels, commonly called "sloughs," and its bed is sand, gravel, and fine silt. Twenty-five miles below the entrance of St. Croix River it broadens in a body of water called Lake Pepin, about 23 miles long and 3 miles wide, through which there is a gentle current at all times. Below

Lake Pepin it again assumes its character as a stream of many channels. It is joined immediately by Chippewa River from the east, and a few miles farther down by Zumbro River from the west.

In the 172 miles from the mouth of Minnesota River to the Iowa boundary, Mississippi River falls a little over 72 feet, making an average slope of 0.42 foot per mile (see fig. 1). Lake Pepin, through which there is practically no fall, is seemingly an excellent place for the sedimentation and destruction of polluting matter received from the large cities upon its banks. At flood times, however, the water passes along swiftly and probably gets little purification between St. Paul and La Crosse.

Tributaries of Mississippi River.—The three larger tributaries on the west side below Minnesota River are Cannon, Zumbro, and Root rivers. The first, having its source in the northwestern part of Rice County, after performing a semicircle through Lesueur County, flows northeastward to Mississippi River near Red Wing. Straight River, its chief tributary, rises in the southern part of Steele County and, flowing northward, joins Cannon River at Faribault. Cannon River below this point is 80 to 85 feet wide and flows in a series of rapids and reaches of smooth water. Ten miles below Cannon Falls the stream becomes narrow, deep, and tortuous as it sinks to the alluvial plain bordering the main stream. Zumbro River is formed by the junction of three small branches in Wabasha County. In its upper part there are many rapids and shoals, but as it emerges from the high bluffs bordering Mississippi River the rapids become fewer and the stream deepens and grows winding, like the other tributaries. Root River rises in Mower County in two branches, which unite in Olmsted County, after which the river pursues an easterly course across Fillmore and Houston counties to its confluence with Mississippi River, a few miles above the State border. Chippewa and Black rivers are important streams that drain a large part of Wisconsin below Lake Pepin.

Topography.—The southeastern part of Minnesota is rolling prairie, bounded on the east by the wide, deeply eroded valley of Mississippi River, which is intersected at different points by large trenches bearing tributary streams. The area is now devoted to the cultivation of corn and wheat. The number of lakes in this section is small as compared with those in other parts of the State.

Geology.—The Archean and the Algonkian rocks, so common in other parts of the State, are not exposed below Minneapolis. Conspicuous formations throughout the counties in this part of the State are the sandstones and limestones of the Ordovician and the Cambrian. The "St. Croix" sandstone appears along the valley of Mississippi River. The coarse, friable St. Peter sandstone outcrops here and, gently dipping southward, becomes an important aquifer in the

artesian basin of Iowa. Rocks of Trenton age, mainly limesto occur all over the region, particularly in the southern count Occasional deposits belonging to the Cretaceous period appear in western part of the basin, and Devonian rocks are found in the sou ern part of Mower and Fillmore counties. Drift of varying thickn covers all except about 3,000 square miles in the southeast corner the State, which unites with similar country in Wisconsin, Iowa, Illinois to form the "Driftless Area." The drift is thickest in the west part, where it is similar in character to that found in Minnesota Vall being mainly blue till. Toward the east it becomes thinner gradually blends with the red till. In the deep river bottoms stra fied alluvial deposits of sand and gravel are found.

Soil and subsoil.—The soil and subsoil are similar to those of Minn sota River basin in chemical composition. They show a fair perce age of alkaline and alkaline-earth ingredients, though true "alkal soils are not found. Toward the east they gradually lose this ch acteristic and contain less and less soluble ingredients.

INDUSTRIAL POLLUTION.

From lower Mississippi Valley there have been reported as likely furnish effluents of undesirable character the following establishments

TABLE 49.—*Industrial establishments causing stream pollution in lower Mississippi Riv basin in Minnesota.*

Breweries	[illegible]
Gas works	[illegible]
Sawmills	[illegible]
Tanneries	[illegible]
Woolen mills	[illegible]

Several large breweries are included in this list, and their effluents are all discharged into Mississippi River and its tributaries either directly or through the city sewers. This waste contains considerable nitrogenous matter that is capable of offensive putrefaction. The gas-works wastes vary according to the character of the process used and the care with which valuable ingredients are recovered. By-products in the manufacture of coal gas are coke, ammonia, and tar. The latter two, in liquid form, are sometimes discharged into streams though this procedure is wasteful and is not countenanced by progressive establishments. The larger sawmills along Mississippi River use considerably less lumber than those on the upper tributaries. The tannery wastes are spent bark liquors, vat sludges, lime, and wash waters containing bits of flesh, hair, and other putrescible matter. Although there has been no complaint on this account, the same kind of pollution has caused a great deal of trouble in other parts of the United States and is likely to become a public nuisance if the establishments increase in size. The three woolen mills noted ar

small, and the wastes that reach the streams are wool scourings, soapy water, and waste dye liquors. The abattoirs, packing houses, rendering works, and stockyards of the slaughtering establishments at St. Paul discharge a great deal of objectionable material through private sewerage systems into Mississippi River. The pollution consists, mainly, of foul, bloody, wash water, yard drainage, and putrescent scraps of animal matter that pass through the skimming tanks. If Minneapolis, just above St. Paul, is included, the manufacturing establishments in this region exceed in number, size, and value of output all those in the rest of the State.

MUNICIPAL POLLUTION.

Population and sources of pollution.—Lower Mississippi Valley in Minnesota was the first part of the State to be settled and is now the most densely populated. Twenty-six towns (see Pl. IV) exceeding 1,000 population are situated in the valley, and the country surrounding them is well occupied by homesteads. The following table shows the distribution of population by counties:

TABLE 50.—*Population of Mississippi River basin in Minnesota below the mouth of Minnesota River, excluding St. Croix River basin.*[a]

County.	U. S. census of 1890.	U. S. census of 1900.	State census of 1905.
Dakota	17,368	18,848	20,299
Dodge	8,890	10,896	10,415
Fillmore	25,996	28,238	27,216
Goodhue	28,806	31,137	31,628
Houston	14,653	15,400	15,092
Lesueur	3,390	3,772	3,796
Mower	4,706	5,620	5,286
Olmsted	19,806	23,119	22,409
Ramsey	136,476	166,809	201,676
Rice	23,786	25,831	25,943
Steele	11,821	14,922	14,984
Wabasha	16,972	18,924	18,710
Washington	2,684	2,812	2,976
Waseca	1,650	1,733	1,608
Winona	33,797	35,686	35,836
Total population	350,771	403,747	437,874

[a] The statistics of population in St. Croix River basin are given in Table 44, p. 90.

TABLE 51.—*Density of population in Mississippi River basin in Minnesota.*

	Drainage area.	Inhabitants per square mile.		
		1890.	1900.	1905.
	Sq. miles.			
Mississippi River basin above Minnesota River	[a] 19,731	19.8	26.9	32.1
Minnesota River basin	[a] 16,350	15.7	25.1	26.0
St. Croix River basin	[b] 7,655	11.1	15.5	18.5
Mississippi River basin above foot of Lake Pepin:				
Entire area	[c] 46,586	21.9	28.5	32.3
Excluding chief settlements		12.2	16.4	17.9
Lower Mississippi basin in Minnesota:				
Entire area	[d] 6,260	56.0	64.5	69.9
Excluding chief settlements		23.9	25.3	24.6

[a] Ann. Rept. Chief of Engineers, U. S. Army, 1894, pt. 3, p. 1704.
[b] Gannett, Henry, Bull. 1, Twelfth Census U. S.
[c] Measured from best available maps.
[d] Hall, C. W., Geography and Geology of Minnesota, vol. 1, p. 151.

Mississippi River above the foot of Lake Pepin is the most heavily polluted stream in Minnesota, as is shown by the following table, which gives the names of the principal settlements above this point, the distance of each above the foot of the lake, and the population for three successive censuses.

TABLE 52.—*Principal settlements in Mississippi River basin above the foot of Lake Pepin.*

Locality.	Stream.	Distance above foot of Lake Pepin.	Population.		
			1890.	1900.	1905.
		Miles.			
Belle Plaine	Minnesota River	132	814	1,121	1,301
Cannon Falls	Cannon River	46	1,078	1,239	1,400
Chaska	Minnesota River	110	2,210	2,165	2,065
Faribault	Cannon River	73	6,520	7,868	8,279
Ellsworth, Wis		39	670	1,052	1,064
Hastings	Mississippi River	51	3,705	3,811	3,810
Hudson, Wis	St. Croix River	63	2,885	3,259	3,220
Jordan	Sand Creek	120	1,233	1,270	1,311
Lake City	Mississippi River	10	2,128	2,744	2,977
Minneapolis	do	89	164,738	202,718	261,974
New Richmond, Wis	Willow River	78	1,408	1,631	1,834
Northfield	Cannon River	62	2,659	3,210	3,438
North St. Paul		83	1,099	1,110	1,400
Owatonna	Straight River	93	3,849	5,561	5,651
Prescott, Wis	St. Croix River	48	911	1,002	889
Red Wing	Mississippi River	26	6,294	7,525	8,149
River Falls, Wis	Kinnickinnic Creek	60	1,783	2,008	2,300
St. Paul	Mississippi River	77	133,156	163,065	197,023
Shakopee	Minnesota River	106	1,757	2,047	2,069
South St. Paul	Mississippi River	73	2,242	2,322	3,458
Stillwater	St. Croix River	71	12,004	12,318	12,435
South Stillwater	do	68	1,453	1,422	1,572
Waterville	Cannon River	93	937	1,260	1,383
West St. Paul	Mississippi River	77	1,596	1,830	2,100
Total			357,129	433,558	531,068

By reference to this list and to Table 51 [a] the position of pollution foci on the three great streams which unite to form lower Mississippi River and the relative danger from human habitations on this watershed can be seen. Upper Mississippi Valley is the largest area and has also the greatest density of population. Minneapolis in that basin is the chief pollution center. St. Croix drainage area, the smallest basin, has the smallest number of inhabitants per square mile. The number of inhabitants per square mile above Lake Pepin for the entire area is 32.3; in the same basin, excluding the chief settlements, it is 17.9. This means that nearly one-half of the population above Lake Pepin is concentrated in sewered cities. With a population of over 450,000 in two cities 60 miles above the head of the lake, there is no need for analysis of the water to establish its pollution and the necessity for artificial purification before it is used for domestic supply. Practical experiments at the price of human lives have demonstrated that the so-called self-purifying power of streams is too precarious a safeguard against water-borne disease. There can be no doubt that sewage discharged into Mississippi River at St. Paul or at Minneapolis has time

[a] See also Pls. II, III, and IV.

to reach Lake Pepin before the death of pathogenic organisms in it. There is, therefore, a flow of highly polluted water into the lake. In its comparatively slow journey of 23 miles through this broad body of water considerable organic matter is destroyed during ordinary water stages. When the spring freshets are in progress and the current is accelerated, Lake Pepin is no longer a sedimentation basin and the water passes through it in its worst sanitary condition, with practically no purification.

In lower Mississippi basin in Minnesota there are 26 settlements having a population exceeding 1,000, and among these are some of the largest cities in the State. These cities and villages are given in the following list:

TABLE 53.—*Settlements in Mississippi River basin in Minnesota, below Minnesota River.*

Locality.	Stream.	Distance above State line.	Population.		
			1890	1900.	1905.
		Miles.			
Caledonia	Crooked Creek	22	927	1,175	1,405
Cannon Falls	Cannon River	138	1,078	1,239	1,460
Chatfield	Mill Creek	100	1,335	1,426	1,300
Faribault	Cannon River	165	6,520	7,868	8,279
Hastings	Mississippi River	145	3,705	3,811	3,810
Kasson	Branch of Zumbro River	150	992	1,112	1,049
Kenyon	do	115	666	1,202	1,252
Lake City	Mississippi River	100	2,128	2,744	2,877
Lanesboro	Root River	65	898	1,102	1,041
Northfield	Cannon River	154	2,659	3,210	3,438
North St. Paul		180	1,099	1,110	1,405
Owatonna	Straight River	185	3,849	5,561	5,651
Plainview		45		1,038	1,140
Preston	Root River	80		1,278	1,320
Red Wing	Mississippi River	118	6,294	7,525	8,140
Rochester	Zumbro River	145	5,321	6,843	7,233
Rushford	Root River	50	968	1,062	1,133
St. Charles	White River	45	1,178	1,304	1,238
St. Paul	Mississippi River	170	133,156	163,065	197,023
South St. Paul	do	165	2,242	2,322	3,458
Spring Valley	Spring Valley Creek	100	1,381	1,770	1,573
Wabasha	Mississippi River	90	2,487	2,528	2,619
Waterville	Cannon River	185	937	1,260	1,383
West St. Paul	Mississippi River	170	1,596	1,830	2,100
Winona	do	51	18,208	19,714	20,334
Zumbrota	Zumbro River	135	867	1,119	1,129
Total			200,491	242,792	495,933

With 70 inhabitants per square mile this is the most densely populated district of the State, and over one-half of this number are in cities, one of which, St. Paul, is the city second in size in Minnesota. Most of the settlements are old; some have reached their maximum development and are now decreasing in size. In general they do not show such advance in sanitary matters as do similar communities elsewhere in the State, for of the 32 principal settlements 7 have no public waterworks, 2 have waterworks for fire protection only, and only 13 have public sewerage.

Typhoid fever.—Records of typhoid fever are extremely fragmentary, and do not adequately represent its true prevalence. The disease is frequently found both in the cities and in the country.

Although some cases are imported, the spread of the disease and its general continuation is probably due to unsanitary conditions in the small villages and to the lack of proper sewage disposal, on account of which the shallow wells used as sources of supply become infected.

QUALITY OF WATER.

The Mississippi unites with the Minnesota just above St. Paul. Thirty-two miles farther downstream the St. Croix enters the Mississippi from the north. Both tributaries are large and the water from each of them constitutes an appreciable percentage of the flow of the main stream. As a result, therefore, the water of the lower Mississippi River shows a quality that is less representative of the region immediately bordering its banks than of the three great areas from which its headwaters are derived. The dissolved and suspended ingredients not only have this composite nature but the amount of each constituent varies measurably with the rise and fall of the tributary that introduces it. A sudden rainfall in upper Mississippi basin causes a flood and a resultant increase of flow at Winona; the percentage of water from upper Mississippi drainage area is relatively increased and the mineral constituents that are most abundant in that region will be found to increase in Mississippi River at Winona. A freshet on Minnesota River causes a similar fluctuation in the ingredients peculiar to that locality. Table 54 gives general averages for the various estimates made on the waters of the three tributaries, together with the size of each drainage area.

TABLE 54.—*Quality of water of chief confluents of lower Mississippi River.*

[Parts per million.]

Determination.	Upper Mississippi River (drainage area 19,731 square miles).	Minnesota River (drainage area 16,350 square miles).	St. Croix River (drainage area 7,655 square miles).
Color	50	30	70
Odor	2 v.	.....	2 v.
Turbidity	<7	70	14
Chlorine	.9	6.4	1.0
Sulphuric acid	Trace.	178	Trace.
Alkalinity	151	220	90
Total hardness	136	470	80
Iron	Trace.	Trace.	Trace
Total residue	189	556	135
Soluble residue	16	143	9
Free ammonia	.191	.193	.004
Albuminoid ammonia	.475	.454	.228
Nitrates	.05	.16	.05
Nitrites	.000	.009	.000

By comparison of the figures it is seen that:

1. Upper Mississippi and Minnesota basins are nearly equal in size while St. Croix basin is less than half as large as either of the other two. This comparison gives some idea of the relative amount of discharge from each stream.

2. The water of St. Croix River is higher in color and generally lower than that of the other two streams in all other amounts estimated. The difference is especially noticeable in alkalinity, total hardness, and residues.

3. The water of upper Mississippi River is higher than that of St. Croix River but much lower than that of Minnesota River in alkalinity, total hardness, and residues.

4. Minnesota River water has the lowest color, the greatest amount of suspended matter, and the highest mineral solids.

It is to be expected, therefore, that increased discharge from Minnesota River will increase the mineral content of the lower Mississippi and will cause especially a rise in turbidity and alkalinity. An increased discharge from St. Croix River, on the other hand, will cause an increase in color but will lower the percentage of mineral matter.

The average quality of upper Mississippi River water, as shown in Table 54, is determined from analyses made above Minneapolis and consequently above the pollution introduced from that place. It is probable, therefore, that the nitrogen determinations made do not represent the quality of the water just above the mouth of Minnesota River. In other constituents, however, the averages are representative. In Table 55, giving the results of analyses of water in Lower Mississippi Valley at different points,[a] there may be found assays of Mississippi River at Hastings. Since this sampling station lies between the mouths of Minnesota and St. Croix rivers, it represents the condition of the stream after its confluence with Minnesota River and shows the effect of that stream. The turbidity, chlorine, sulphuric acid, alkalinity, total hardness, total residue, and soluble residue are all greater than in the Mississippi above Minneapolis, and the water has a different appearance. Beside the entrance of strongly mineralized water from Minnesota River it has received gross pollution, which appears as decomposing sewage and other refuse, from a population of over 450,000 at Minneapolis and St. Paul. The examinations made at Red Wing show the quality of the water just above the head of Lake Pepin and below the mouth of St. Croix River. Comparison with examinations made at Hastings shows that sulphuric acid, chlorine, total alkalinity, total hardness, and total residue are decreased by the introduction of the soft water of St. Croix River. The examinations at Wabasha do not reveal a greater change in mineral content than might be expected by reason of the introduction of water from small tributaries.

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[a] See Pl. I for location of sampling stations.

TABLE 55.—*Quality of water in lower Mississippi River basin.*

[Parts per million.]

Locality and source.	Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Total alkalinity.	Total hardness.	Iron.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Bacteria per c.c.[a]	B. coli communis.[a]
Mississippi River:																	
At Hastings	Aug. 29, 1903															3,000	+
Above Wabasha[b]	do	0	0		3				0	210		0.44	0.48	0.00	0.5	200	+
At Hastings[c]	June 8, 1904							168				.27	.08	.00	Distinct.	10,500	+
At Hastings[d]	Oct. 14, 1904	44	3 v	19	2.2	e 15	140	160	0	209	24	.312	.138	.000	.05	3,800	+
Below Red Wing[d]	Oct. 13, 1904	40	2 v	15	1.3	e 10	124	132	0	169	20	.264	.092	.000	.05	3,000	+
Above Wabasha[d]	do	25	2 v	15	2.4	e 15	141	160	0	192	20	.260	.060	Trace.	.05	200	+
At Hastings[d]	Feb. 10, 1905	29	2 M	12	5.3	25	228	233	Trace.	297	32	.328	.360	.010	.23	4,000	+
Below Red Wing[d]	Feb. 11, 1905	29	2 M	10	4.6	e 20	190	194	Trace.	238	30	.282	.320	.009	.23	2,200	+
Above Wabasha[d]	do	29	0	e 10	3.3	e 15	175	174	Trace.	224	16	.238	.196	Trace.	.25	60	−
Zumbro River:																	
Above Rochester[b]	Aug. 28, 1903	0	0		7				0	200		.8	Trace.	Trace.	.5	6,100	−
Above mouth[b]	Aug. 29, 1903	0	0		10		130		0	220		.4	.35	Trace.	1.0	1,300	−
Above Rochester[c]	May 4, 1904				1.7									Trace.	Distinct.	700	+
Below Rochester[c]	do				3.5									Distinct.	Distinct.	7,000	+
Above Rochester[c]	July 15, 1904				2.1							.18	.22	Trace.	Distinct.	1,000	+
Below Rochester[c]	do				5.2							.24	.36	Distinct.	Distinct.	5,500	+
Above Rochester[d]	Aug. 17, 1904	18	2 v	e 10	2.6		221	187		271		.200	.290	.00	.05	1,600	+
Below Rochester[d]	do	18	2 M	e 20	7.3		226	187		272		.262	.480	.05	5.0		+
At mouth[d]	Oct. 14, 1904	18	2 e + 1 v	60	2.2	15	214	230	0	279	28	.206	.102	.015	.12	2,800	+
At mouth[d]	Feb. 11, 1905	4	0	<7	2.0	e 10	250	230	Trace.	278	46					450	−
Bear Creek at Rochester[c]	May 4, 1904													Distinct.	Distinct.	650	+
Bear Creek at Rochester	Aug. 17, 1904	4	3 M	e 15	2.6		209	215		265		.148	.170	.025	8.4	4,200	+
Pool at mouth of sewer Owatonna[d]	Nov. 29, 1904	44			18.2	e 15	416	529	0.5	497	139	2.30	15.7	.073		120,000	+
Straight River above Owatonna[d]	do	4			2.6	d 5	306	418	Trace.	340	24	.186	.034	.000	.02	3,000	+
Straight River below Owatonna[d]	do	24			6.8	d 5	318	418	Trace.	390	37	.316	.270	.008	0.9	11,000	+

[a] Bacteriological examinations by Dr. E. H. Beckman.
[b] Analysis by Dr. E. H. Beckman.
[c] Analysis by H. C. Carel.
[d] Analysis by R. B. Dole.
[e] Estimated.

The condition of the organic matter in the lower stream is distinctly different from that in the river above Minneapolis. Though the river has received an enormous amount of sewage, the albuminoid ammonia averages less than in upper Mississippi River. Free ammonia is, however, higher, and nitrites are usually found, and both ammonias vary considerably from time to time. In winter nitrites are generally found. The evidence of fecal pollution is more positive from the bacteriological examinations, which show enormous numbers of bacteria in nearly every sample examined. *B. coli communis* was isolated in pure culture from all but three of the bacteriological samples taken in lower Mississippi basin, and this fact indicates a general presence of pollution. It is unfortunate that more detailed data could not be obtained regarding the possible purification of the water during its passage through Lake Pepin. In October, 1904, Mississippi River was about 5 feet above its normal level at Wabasha, and the water passed swiftly through Lake Pepin. The samples taken at that time show no appreciable decrease in the amount of organic matter nor a great change in its condition. Water from the foot of the lake revealed a trace of nitrites, which did not appear at the head, and the number of bacteria per cubic centimeter was lower The presence of *B. coli communis*, however, was established. In February, 1905, samples taken at the same points did show an apparent oxidation of organic matter by a reduction of the albuminoid ammonia, free ammonia, and nitrites, and a slight increase in nitrates. The number of bacteria was reduced, and *B. coli communis* was not isolated. It should be remarked in this connection, however, that only 1 cubic centimeter of water was examined for this bacillus, and it is possible that it might have been found if larger amounts of water had been used.

Examinations were made of Zumbro River at Rochester and above its mouth, near Wabasha. Since this stream drains prairie country, its quality fluctuates greatly with the season and the amount of local precipitation. Heavy rains cause sudden floods in it, which are accompanied by great increase of turbidity and organic matter, due to the scouring effect of the current on its easily disintegrated banks and bed. In winter the water of the stream was found to be clear and sparkling and to contain a considerable amount of mineral matter, as is shown by the alkalinity and total residue. In the fall it was in flood, and the estimates show flood conditions. There is an increase of mineral matter during its course to the Mississippi. All examinations showed large numbers of bacteria, and *B. coli communis* was isolated in every case but one. Straight River was examined during the latter part of November, 1904, when the stream was frozen. It has a high mineral content, and its bacterial condition indicates pollution. There is an increase of organic matter at Owatonna.

In 1882 considerable excitement was caused at Waterville by the existence of supposed poisonous algæ in Lake Tetonka and other ponds in that vicinity. Samples of the organisms were examined microscopically by Prof. J. C. Arthur, who has fully reported the incident. The death of several cattle was attributed to this plant without any experimental basis for the popular belief, which was not concurred in by the above-mentioned author.

Mississippi River below Red Wing may be said to vary in its quality according to the fluctuations of St. Croix, Minnesota, and upper Mississippi rivers. If examinations were extended from that point to the State border, the river would doubtless be found to increase in mineral content on account of drainage from the limestone formations in this area. The river is grossly polluted, and the sewage introduced has not disappeared by the time the water reaches Wabasha. It would be decidedly dangerous for domestic consumption without purification. The following table gives a summary of the examinations made.

TABLE 56.—*Summary of quality of water of lower Mississippi River.*

[Parts per million.]

Determination.	Maximum.	Average.	Minimum.
Color	44	28	25
Odor	2 M	2 v+1 M	0
Turbidity	19	13	10
Chlorine	5.3	3.1	1.3
Sulphate radicle	25	16	10
Alkalinity	228	166	124
Total hardness	233	174	132
Iron	Trace.	Trace.	0
Total residue	297	219	169
Soluble residue	32	23	16
Free ammonia	0.48	0.218	0.08
Albuminoid ammonia	0.44	0.311	0.23
Nitrates	0.25	0.13	0.05
Nitrites	0.010	Trace.	0.00

NOTES ON MUNICIPALITIES.

Twenty-two of the thirty-two settlements in the basin use ground water, one is supplied with river water, and one is supplied with both well and lake water. Eleven cities and villages are equipped with sanitary sewerage.

Caledonia, Houston County.—On a small creek entering Mississippi River. Water supply is obtained from an 8-inch well, 318 feet deep, passing through clay, 40 feet; hard sandstone, 30 feet; limestone, 130 feet; soft sand rock, 118 feet. Ice supply is cut from Crooked Creek and from one of the sloughs connected with Mississippi River. No sewerage system. Garbage is taken outside the city.

[a] Arthur, J. C., Some algæ of Minnesota supposed to be poisonous: Bull. Minn. Acad. Nat. Sci., 1880-83, vol. 2, Bull. 4, Appendix 1. Also A supposed poisonous seaweed in the lakes of Minnesota: Proc. Am. Assoc. Adv. Sci., 1883, vol. 32, p. 305.

Cannon Falls, Goodhue County.—On Cannon River, 20 miles above Mississippi River, at the mouth of Little Cannon River. Water supply is obtained from an 8-inch artesian well, 400 feet deep; ice supply from Cannon River. A sanitary sewerage system discharges into Little Cannon River. Garbage is hauled to the public dumping ground outside the city.

Chatfield, Fillmore County.—On Mill Creek just above the north branch of Root River. Water supply is procured from a 6-inch well, 200 feet deep, drilled through sand rock and limestone; ice supply from Root River above the city drainage. No sewerage. Offensive garbage is hauled outside the city and buried.

Claremont, Dodge County.—Near a branch of Zumbro River, to which it drains. No waterworks. Ice supply is cut from Zumbro River and Rice Lake. Storm sewerage is installed.

Dakota City, Winona County.—On Mississippi River, 18 miles below Winona. No waterworks or sewerage.

Dodge Center, Dodge County.—A short distance from the south middle branch of Zumbro River. No waterworks. Ice supply taken from Zumbro River. No sewerage. Garbage and night-soil commonly used on adjacent farms.

Faribault, Rice County.—On Cannon River at its confluence with Straight River, 27 miles above Cannon Falls. Water supply is obtained from two artesian wells 800 and 700 feet deep, respectively, and from two surface wells with uncemented brick walls 20 feet deep. Ice supply is cut from Cannon and Straight rivers. Sanitary sewerage discharges into Cannon River. Garbage is hauled to a dumping ground on the outskirts of the city. Shattuck School for Boys, 200 pupils; St. Mary's Hall for Girls, 100 pupils; Bethlehem Academy for Girls, 70 pupils; State School for the Deaf, 300 pupils; State School for the Blind, 100 pupils; State School for the Feeble-minded, 1,000 pupils, are all located within or near the city. These institutions are supplied with city water and connected with the city sewerage.[a]

Farmington, Dakota County.—On Vermilion Creek, about 20 miles above its entrance into Mississippi River. No waterworks or sewerage. Ice supply is cut from Vermilion Creek. Garbage is removed to a dumping ground just outside the village limits.

Hastings, Dakota County.—On Mississippi River, 3 miles above its confluence with St. Croix River. No waterworks or sewerage. Ice supply is cut from Mississippi River, Lake St. Croix, and Lake Rebecca. Garbage is hauled to the dumping ground outside the city. The Second State Asylum for the Insane is located about 2 miles from Hastings. It has a private water supply, derived from a deep well, and a sanitary sewerage system discharging into Mississippi River.

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[a] Biennial Rept. Minnesota State Board of Health, 1901-02, p. 284.

Kasson, Dodge County.—On a small creek about 3 miles above its entrance into the south middle branch of Zumbro River. Water supply is obtained from an 8-inch well, 200 feet deep, drilled into the rock; ice supply from small branches of Zumbro River. Storm sewerage, but no sanitary sewerage has been installed.

Kenyon, Goodhue County.—On north branch of Zumbro River, 20 miles above Zumbrota. Water supply is taken from a well 25 feet deep; ice supply from Zumbro River. No sewerage. Garbage is hauled to a public dumping ground east of the city.

Lake City, Wabasha County.—On the shore of Lake Pepin, 20 miles below Red Wing. Water supply is obtained from a dug well in the village. There is also an emergency connection with Lake Pepin. Ice supply is cut from Lake Pepin. A combined sewerage system discharges into Lake Pepin.

Lanesboro, Fillmore County.—On Root River, 45 miles above its confluence with Mississippi River. Water supply is procured from a spring near the village; ice supply from south branch of Root River above the mill-pond dam. No sewerage. Garbage is dumped on a lot outside the corporation limits.

Northfield, Rice County.—On Cannon River, 6 miles above Cannon Falls. Water supply is obtained from an 8-inch artesian well, 640 feet deep, drilled through the following strata:

Log of well at Northfield.

	Feet.
Lime rock	265
Sand rock	50
Shale	225
Sand rock	20
Shale	3
Sand rock	15
Shale	9
Sand rock	35
Lime rock	25

Ice supply is cut from Cannon River. A sanitary sewerage system discharges into Cannon River. Garbage is hauled to a dumping ground outside the city.

North St. Paul, Ramsey County.—Near the city of St. Paul. Water supply is obtained from an 8-inch well, 300 feet deep. There is also an emergency connection with an adjacent lake. Ice supply is cut from a lake south of town. No sewerage. There is no regular garbage disposal; it is usually burned by individual householders.

Owatonna, Steele County.—On Straight River, 20 miles above Faribault. Water supply is procured from five drilled wells—three 8-inch wells, 120 feet deep; one 5-inch well, 90 feet deep; and one 8-inch well, 650 feet deep, all entering rock at 40 feet. The 120-foot wells are driven in the bottom of a dug well 20 feet by 27 feet. Ice

supply is cut from Straight River, above the mill dam. A sewerage system discharges into Straight River. Garbage is removed to the public dumping ground. The State School for Dependent and Neglected Children, with 250 pupils, is located at Owatonna. Its water supply is taken from two 6-inch wells, 260 feet deep, and it has also a private sewerage system entering the river.

Plainview, Wabasha County.—Water supply is procured from two deep wells, 4¾ inches by 335 feet and 5¾ inches by 700 feet, respectively. They penetrate 60 feet of clay and are then drilled through limestone and sandstone. No sewerage.

Preston, Fillmore County.—On South Branch of Root River, 60 miles above its entrance into Mississippi River. Water supply is obtained from a spring near the village, inclosed with rock and cement, and covered. Ice supply is cut from Root River. No sewerage. Garbage is hauled to a public dumping ground 1 mile below the town.

Red Wing, Goodhue County.—On Mississippi River, just above the head of Lake Pepin. Water supply for fire protection only is taken from Mississippi River; ice supply from Mississippi River. Sewerage discharges into Mississippi River. Garbage is removed by a public scavenger and buried at the city dumping grounds. The Red Wing Seminary, 130 pupils; Lutheran Ladies Seminary, 200 pupils, and the State Training School, with about 400 inmates, are located in or near Red Wing. The water supply for the training school is taken from a surface well 15 feet in diameter, sunk in the sand near the river, and a sewerage system discharges into Mississippi River.[a]

Rochester, Olmsted County.—On Zumbro River, at its confluence with Bear Creek. Water supply is obtained from driven points and a bricked well 30 feet in diameter by 30 feet deep on the banks of Bear Creek, near its confluence with Zumbro River. There is also an emergency connection to Bear Creek. Sewerage discharges into Zumbro River. The Second State Hospital for the Insane (about 1,300 inmates) is situated 1¼ miles east from the center of the town, near a small creek. The water supply is obtained from four 8-inch wells. The private sewerage system is equipped with a disposal plant designed to purify the sewage by precipitation and intermittent filtration.[b]

Rushford, Fillmore County.—On Root River, at the entrance of Rush Creek. Water supply is procured from a 6-inch flowing well, 565 feet deep, in limestone and sandstone; ice supply from Root River. A sanitary sewerage system is installed, discharging into Rush Creek. Garbage is commonly thrown into the river.

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[a] Biennial Rept. Minn. State Board of Health, 1901-2, p. 280.

[b] Rafter and Baker, Sewage Disposal in the United States, second edition, p. 500; Biennial Rept. Minn. State Board Health, 1901-2, p. 277; Engineering and Building Rec., vol. 23, p. 72.

St. Charles, Winona County.—On Whitewater River, 25 miles above Mississippi River. Water supply is obtained from a 10-inch well, 942 feet deep, in sandstone. No sewerage. Garbage is hauled to a dumping ground 1 mile from the city.

St. Paul, Ramsey County.—On Mississippi River, just below the entrance of Minnesota River. The city water supply is both surface and ground water, though the greater part is from lakes. The wells, 37 in all, with depths varying from 63 to 85 feet, are put down on the shore of Vadnais and Centerville lakes. The surface supply is taken from 22 small lakes, 5 to 20 miles away from the city, principally from Phalen, Vadnais, and Pleasant lakes.[a] Ice supply is cut from Minnetonka, White Bear, Phalen, Bass, McCarrons, and Long lakes, and from Minnesota River, just above Fort Snelling. Sanitary and storm sewerage discharges into Mississippi River. Part of the city garbage is dumped into Mississippi River, but most of it is sold to farmers for fertilizer.

South St. Paul, Dakota County.—On Mississippi River, just below St. Paul. Water for the public supply is furnished from private artesian wells at Swift & Co.'s packing house. Ice supply is cut from small lakes in the vicinity. No sewerage. Garbage is hauled to the stock yards and dumped near the river.

Spring Valley, Fillmore County.—On Spring Valley Creek, which enters the middle branch of Root River. Water supply is procured from a spring a short distance from the pumping station; ice supply from Deer Creek, 3 miles north of the city. A combined sewerage system discharges into Spring Valley Creek. Garbage is removed to a dumping ground, where it is buried at intervals.

Stewartville, Olmsted County.—On Root River. Water supply is obtained from an 8-inch well drilled 62 feet in the rock; ice supply from the river. No sewerage. Garbage is hauled to the village dumping ground.

Wabasha, Wabasha County.—On Mississippi River, just below the foot of Lake Pepin. No water supply or sewerage. Ice supply is cut from Mississippi River above the town. Garbage is generally burned, though some is dumped into the river.

Waterville, Lesueur County.—Between Lakes Tetonka and Sakata, through which Cannon River flows. Water supply is procured from an 8-inch drilled well, 185 feet deep; ice supply from Lake Sakata. No sewerage. Garbage is removed to a public dumping ground, where animal matter is usually burned and other refuse buried.

West Concord, Dodge County.—On north middle branch of Zumbro River. Water supply for fire protection. No sewerage.

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[a] Fanning, M. G., Observations on the algæ of the St. Paul city water: Minnesota Botanical Studies, second series, pt. 5, July 20, 1901, p. 609.

West St. Paul, Dakota County.—On Mississippi River, opposite St. Paul. No waterworks or sewerage; ice supply from Thompson and Sunfish lakes. No regular garbage disposal.

Winona, Winona County.—On Mississippi River, 51 miles above the southern State boundary. Water supply is obtained from two shallow wells in Riverside Park near the river. There is an emergency connection from Mississippi River to the north shallow well. Ice supply is cut from Mississippi River and Lake Winona. Separate storm and sanitary sewerage equipped with Shone automatic ejectors discharge into Mississippi River. There is no public garbage disposal.

Zumbrota, Goodhue County.—On Zumbro River, 50 miles above its entrance into Mississippi River. Water supply is obtained from a well drilled 210 feet deep into limestone;[a] ice supply from Zumbro River. No sewerage. Garbage is hauled to the public dumping ground.

ST. LOUIS RIVER BASIN.

GENERAL DESCRIPTION.

Boundaries.—This area includes a small but important section in the northeastern part of the State, north and west of Lake Superior. It is bounded on the north by Rainy River drainage area, from which it is separated by the highest elevations in the State. It is bounded on the west and the south by Mississippi basin. On the east are the basins of the minor tributaries of Lake Superior. (Pl. VI.)

Character and slope of St. Louis River.—The streams are in general short and tumultuous. They rise on the slopes of the Mesabi and Sawteeth ranges, and there are many rapids and cataracts in their courses. The largest stream, St. Louis River, has its source in the west-central part of Lake County and flows southwestward across St. Louis County, nearly to its southwest corner, where at its confluence with Floodwood River it turns abruptly and flows southeastward for about 40 miles, then eastward, in which general course it continues to its entrance into Lake Superior at Duluth. Throughout its entire course it is a typical woodland stream, traversing regions in which the pine timber is now standing or from which it has been removed but recently. In most of its course it is swift, broad, and moderately deep, and it receives practically the whole drainage of the Mesabi Range.

Comparatively little data have been published regarding surveys on this stream, so that a proper profile can not be presented. Though it is rather sluggish in its upper section, it has considerable fall in its

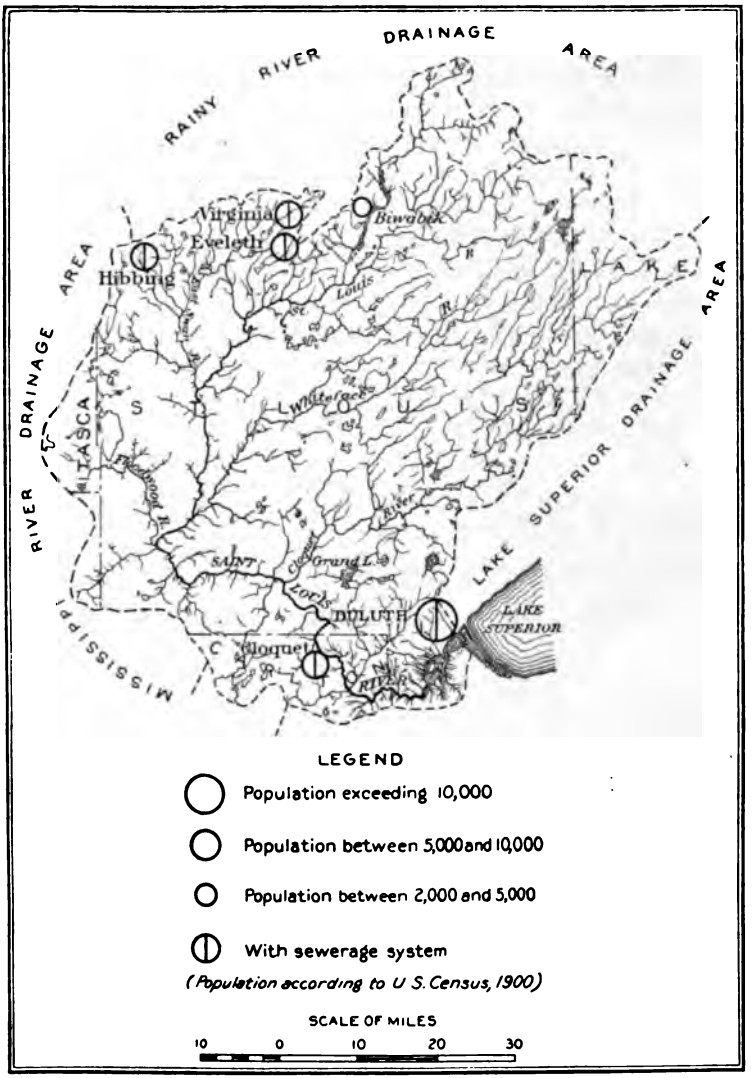
[a] Biennial Rep. Minn. St. Bd. Health, 1901-2, p. 327.

lower part, below the points of entrance of the principal tributa
A survey made by the Corps of Engineers of the United States A
shows the slope of the river from Floodwood to its mouth.[a] B
the entrance of Floodwood River it falls about 40 feet in 6 m
thence to Cloquet Rapids the stream has little descent, but at t
rapids there is a natural fall of 5 feet in less than one-quarter
mile. A short distance below, at Grand Rapids, the river fal
feet in 5 miles. At Knife Falls it drops 20 feet in a very short
tance and has a total fall of 154 feet in less than 5 miles. This po
has been partly utilized at Cloquet. Between these falls and F
du Lac lie the rapids of the St. Louis, in the course of which
river descends about 460 feet. Fond du Lac, appropriately so na
because it is situated at the head of navigation on St. Louis Rive
18 miles above Lake Superior. From this town to Minnesota P
the river widens out into a placid shallow bay, with a barely pe
tible current.

Tributaries of St. Louis River.—The longest tributary of St. L
River is Cloquet River, which rises in Lake County and, flow
southwestward across St. Louis County, enters the main stream n
Cloquet Rapids, a few miles above the village of Cloquet. (See
VI.) The stream is rapid in its upper portion, but becomes less s
after entering the level parts of St. Louis County. Its drainage a
is 675 square miles.[b] Whiteface River lies between Cloquet a
St. Louis rivers and follows the same general direction across S
Louis County, joining the St. Louis near Floodwood. Its drain
area is 534 square miles.[b] East Swan River has its headwaters i
the Mesabi Range, near Hibbing, and flows southward to St. Lo
River. Floodwood River is also a western tributary running south
ward from Itasca County into St. Louis River near Floodwood. I
drainage area is 257 square miles.[b] Embarrass River is a small
tributary, which has its source in the central part of St. Louis Count
and flows southward, crossing the Mesabi Range, passing throug
several long narrow lakes, and entering St. Louis River above Ea
Swan River. Many smaller streams of similar character enter St.
Louis River. Woodland lakes are distributed all over the basin.
They are of moderate depth and are highly colored by the dissolve
vegetable matter that reaches them.

Geology.—The geological features of St. Louis Valley and the rest of
the Lake Superior region have been elsewhere discussed in much
detail.[c] A prominent feature is the line of hills comprising the Saw-
teeth and Mesabi ranges, which form the northern boundary of th

[a] Lake Superior and Mississippi Canal, Exhibit F, H. R. Doc. 330, 54th Cong., 1st sess.
[b] Water Powers of the United States, pt. 2, Tenth Census U. S., p. 72.
[c] Winchell and Grant, Geol. and Nat. Hist. Survey of Minnesota, Final Report, vol. 4, pp. 29
Leith, C. K., The Mesabi Iron-bearing District of Minnesota; Mon., U. S. Geol. Survey, vol. 43.



MAP OF ST. LOUIS RIVER BASIN.

basin and separate its waters from those of the Rainy River system. The rocks of the range are old, belonging almost entirely to the Archean and Algonkian systems. Though generally modified by glacial action, bed rock is widely exposed in these hills and the drift is thin in many places. South of these elevations there is in St. Louis County a broad expanse of level, often swampy land, heavily covered with drift underlain to some extent by Cretaceous formations. Bordering Lake Superior below this plain there is another rugged section exhibiting early rocks of hard, durable character, which cause waterfalls and rapids in the streams that cross them. The most important formations from an economic standpoint are the iron-ore deposits in the Mesabi district, the hydro-economic influences of which are discussed elsewhere.[a] Along the lake shore lava is seen at many places. Granite, micaceous schists, gneisses, and slates are the prevailing rocks all over the area; there is little material to render the drainage water hard and chemical analyses in general show amounts of incrustants so small that the streams of this basin may be ranked with those of the St. Croix as the softest in the State.

INDUSTRIAL POLLUTION.

Little manufacturing is done in the Lake Superior region and few establishments exist which would be likely to pollute the streams.

TABLE 57.—*Industrial establishments causing stream pollution in Lake Superior basin.*

Breweries	2
Gas works	1
Paper mills	1
Sawmills	15
Tanneries	2
Woolen mills	1

Many of these establishments are located at Duluth and their effluents are discharged into Lake Superior. There are five sawmills at Cloquet and there is another large one a short distance below, at Scanlon. These are situated along the banks of St. Louis River and much of their waste goes into that stream. A paper mill and two pulp mills, operated by the Northwest Paper Company, are also located at Cloquet. The ground-wood process is used without chemicals and the capacity of this establishment is about 86,000 pounds a day of news, manila, and hanging paper.[b]

[a] See pp. 25, 115, 116-117.
[b] Post's Paper Mill Directory, 1895-6, p. 191.

TABLE 58.—*Quality of underground waters in the Mesabi Range.*[a]

[Parts per million.]

Locality and source.	Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Alkalinity.	Total hardness.	Iron.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Free CO_2.	Bacteria per cc.	B. coli communis.
Biwabik:																		
Public well	Nov. 29, 1903	0	0	0	.....	0	165	171	.....	.....	.....	.....	.....	.....	.....	.....	17	−
Do.[b]	Feb. 4, 1904	0	2e	0	0.3	Trace.	182	185	.....	.....	.....	0.02	0.015	Absent.	Trace.	.....	6	−
Do.[b]	May 11, 1904	0	0	0	.30	[c]10	182	226	[c]0.5	.....	.....	.02	.01	Absent.	Trace.	.....	44	−
Do	Sept. 19, 1904	0	0	0	1.9	[c]10	202	216	Trace.	254	32	.028	.008	.000	.057	21	74	−
Open-pit mine	Nov. 29, 1903	0	2e	0	.....	Trace.	88	103	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Eveleth:																		
Adams mine[b]	Nov. 27, 1903	3	2e	0	1.25	0	121	171	.....	.....	.....	.01	.01	Absent.	Distinct.	.....	400	+
Do.[b]	Feb. 3, 1904	4	3e+2M	10	0.30	.....	105	.....	.....	.....	.....	.10	.07	Trace.	Distinct.	.....	200	+
Do	May 13, 1904	0	2e	[c]5	.45	Trace.	112	155	0	.....	.....	.01	.08	Trace.	Distinct.	.....	100	+
Spruce mine	Sept. 21, 1904	0	0	0	1.5	Trace.	111	132	0	137	10	.016	.010	.000	.00	26	41	+
Shallow well near Lake Ely	Sept. 12, 1904	0	0	0	4.8	Trace.	78	90	Trace.	109	12	.026	.004	.000	1.20	21	.....	.....
Do	Sept. 20, 1904	0	0	0	4.8	Trace.	69	90	Trace.	122	26	.014	.004	.000	1.25	22	30	−
Hibbing:																		
Old prospecting shaft, public supply	Nov. 25, 1903	4	0	0	.....	0	57	103	.....	.....	.....	.....	.....	.....	.....	.....	170	−
Do.[b]	Feb. 1, 1904	0	0	0	.40	0	67	110	.....	.....	.....	.02	.018	Absent.	Distinct.	.....	20	−
Do	May 14, 1904	0	0	0	.35	0	69	86	0.	.....	.....	.006	.006	Absent.	Distinct.	.....	12	−
Do	Sept. 19, 1904	0	0	0	1.5	Trace.	77	83	0	107	9	Trace.	Trace.	.000	.080	.....	90	−

[a] Analyses by R. B. Dole. Bacteriological examinations by Dr. E. H. Beckman.
[b] Nitrogen and chlorine determinations by H. C. Carel.
[c] Estimated.

Lumbering and mining are the chief industries in the region. Logging was the first attraction for explorers, but that business has been far outranked by iron mining in the Mesabi district. Statistics regarding the extent of this industry are given on page 25, and the hygienic condition of the water in the ore is discussed under the heading "Municipal pollution," on pages 116–117, so that it is here necessary only to speak of the probable effect of the mine drainage on the mineral constituents of the streams. Since the mineral content of natural water is determined by the character of the geologic formations it traverses, the drainage from ore deposits will contain compounds similar to those that are most prominent and most soluble in the ore itself. Analysis of many representative ore samples from the Mesabi district[a] shows that the ores contain from 50 to 60 per cent of iron, 2 or 3 per cent of silica, less than one per cent of calcium and magnesium and small percentages of manganese and aluminum, while the phosphorus and sulphur together seldom exceed 1 per cent. The mine drainage does not therefore seriously affect the quality of the waters for boiler use. Chemical analyses of samples of mine waters corroborate these conclusions. (See Table 58.)

MUNICIPAL POLLUTION.

Lake Superior basin in Minnesota outside of St. Louis County is very thinly settled, so that pollution from human habitations in that region is not yet important. Two Harbors is the only large settlement in Lake County, and the country east of that village is generally wild and uninhabited. Duluth, the chief center of population in St. Louis Valley, owes its growth to its strategic commercial position. The remarkable growth of population in the drainage area north of Duluth during the last twenty-five years has been caused almost entirely by the discovery and the development of the Mesabi iron-bearing district. All of the cities in this area have been established since 1890, and their location and their increase or decrease in population have been coincident with the development of mining properties. The statistics presented in Tables 59–62 indicate the enormous rate at which settlement has taken place.

TABLE 59.—*Population in the Lake Superior basin of Minnesota.*

Area.	U. S. census, 1890.	U. S. census, 1900.	State census, 1905.
St. Louis basin	45,157	78,920	116,875
Cook County	98	810	1,462
Lake County	1,299	4,654	6,275
Pigeon River Indian Reservation	(b)	(b)	362
Total	46,554	84,384	124,974

[a] Leith, C. K., The Mesabi iron-bearing district of Minnesota: Mon. U. S. Geol. Survey, vol. 43.
[b] Included in the population of Cook County.

TABLE 60.—*Population in St. Louis River basin.*

Area.	1890.	1900.	1905.
Carlton County	4,174	7,239	12,069
St. Louis County	39,983	71,681	103,920
Fond du Lac Indian Reservation	(a)	(a)	886
Total	45,157	78,920	116,875

a Included in the population of Carlton County.

TABLE 61.—*Density of population in Lake Superior basin in Minnesota.*

Area.	Drainage area in square miles.	Inhabitants per square mile.		
		1890.	1900.	1905.
Lake Superior basin:				
Entire basin	a7,175	6.5	11.8	17.3
Excluding chief settlements		1.3	2.2	4.1
St. Louis basin:				
Entire basin	b3,700	12.2	21.3	31.6
Excluding chief settlements		2.5	3.6	7.3
Excluding Duluth		3.3	7.0	14.0

a Hall, C. W., Geography and Geology of Minnesota, vol. 1, p. 151.
b Measured from the best available maps.

TABLE 62.—*Principal settlements above Duluth.*

Locality.	Stream.	Distance above Duluth.	Population.		
			1890.a	1900.	1905.
		Miles.			
Biwabik	Embarrass Lake	125	.....	1,299	946
Cloquet	St. Louis River	30	2,530	3,072	6,117
Eveleth	Small creek	100	.....	2,752	5,332
Hibbing	Penobscot Creek	110	.....	2,481	6,566
Virginia	Silver Lake	120	.....	2,962	6,056
				12,566	25,017

a Information regarding population is incomplete.

The Mesabi district, a strip across St. Louis County on the northern border of St. Louis drainage, is the chief mining district of the State and, since mining is the reason for its population, the inhabitants are collected into small villages at the "locations," while the lands around the mines are generally uncultivated and uninhabited. The principal mining towns are Biwabik, Chisholm, Eveleth, Fayal, Hibbing, McKinley, Missabe Mountain, Mountain Iron, Sparta, and Virginia. In some of these places, particularly in Eveleth, the mine water has undoubtedly been the cause of considerable typhoid fever. The porous ore body contains more or less water, which must be removed for successful operation. From the standpoint of the hydraulic engineer it is economical to utilize this water for domestic purposes, but from the sanitarian's standpoint it is dangerous. The mines are

inhabited by large numbers of men, one or two of whom are always likely to have an infectious disease. The miners commonly urinate and defecate in the mines, the drainage from which reaches the sumps, whence the water is pumped to the surface. When this infected water is used for a public supply, serious epidemics usually result. Whether the water from unused shafts is dangerous is a debatable matter, but it should always be regarded with suspicion until a thorough inspection has demonstrated that the shaft which is being utilized is not connected by seams or faults or artificial passageways with a mine in operation. In considering the probable pollution of underground water by the dejecta of miners, it may be noted that *B. coli communis* was isolated in three out of four examinations of the town supply of Eveleth, which was taken from a shaft mine, and was not found in that of Biwabik village, the supply for which is taken from a deep shaft dug for water supply, nor in the supply of Hibbing, which comes from an old prospecting shaft. The cities of Hibbing, Eveleth, and Virginia are equipped with sewerage systems, which discharge into tributaries of St. Louis River. The other towns have no public sewerage as yet, and the use of privies and cesspools is general.

The St. Louis basin, between the Mesabi district and Cloquet, is now but slightly populated and contains much forest and swamp land. Floodwood and Swan River are small villages.

Between Cloquet and Duluth the river basin is more thickly populated on account of the gradual extension of the city suburbs and the development of water powers on the river. Scanlon, Carlton, and Fond du Lac are small villages in this section. The figures given in Table 61, showing the density of population in the basin excluding the chief settlements, do not adequately represent the condition, because it was impossible to learn the population of many of the small villages. As a matter of fact, the population of St. Louis basin is concentrated in Duluth, two or three large sawmill towns, and the mining locations of the Mesabi district. Except these, the region contains only a few scattered farms in its southern part, and the county in general is unsettled.

QUALITY OF WATER.

The first series of samples collected in St. Louis basin was taken in the early winter of 1903, just after the lakes and streams had become icebound. The second series was taken during February, 1904, under similar conditions. The third series was taken in the spring of 1904, just after the ice had gone out, when the stream showed flood conditions at many places. The fourth series was taken in the fall of the same year, while the streams were open. The fifth series was taken at Cloquet during the winter of 1905, while the river was icebound.

TABLE 63.—*Quality of water in St. Louis River basin.*

[Parts per million.]

Locality and source.	Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Total alkalinity.	Total hardness.	Iron.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Bacteria per c. c. [c]	B. coli communis. [c]
Silver Lake at Virginia [a]	Nov. 27, 1903	324	3 v.	10	.....	Trace.	31	62	.....	.....	.....	.....	.....	.....	.....	.....	.....
Do	Feb. 2, 1904	176	4 v.	10	0.5	[d] 10	59	89	.....	.....	.....	0.28	0.206	0.00	Distinct.	700	+
Do	May 14, 1904	120	3 M.	50	.3	.....	44	50	Trace.	.....	.....	.35	.46	Trace.	Trace.	.....	+
Do. [b]	Sept. 21, 1904	86	2 M.	15	3.0	0	80	90	0	135	26	.250	.152	Trace.	Trace.	1,300	+
Virginia Lake at Virginia [a]	May 14, 1904	138	3 M.	50	.3	Trace.	42	50	Trace.	.....	.....	.32	.55	Trace.	Distinct.	6,900	+
Ely Lake at Sparta [a]	Nov. 28, 1903	20	.....	9	.3	0	48	75	.....	.....	.....	.....	.....	.....	.....	80	−
Do	Feb. 3, 1904	18	0	0	.3	Trace.	56	89	.....	.....	.....	.21	.07	Trace.	Distinct.	10	−
Do	May 11, 1904	18	.....	0	.3	0	49	78	0	.....	.....	.27	.08	.00	Trace.	250	−
Do. [b]	Sept. 20, 1904	18	2 v.	<7	1.8	Trace.	58	62	Trace.	92	14	.212	.036	.000	.015	20	−
Silver Lake at Eveleth [a]	May 12, 1904	18	0	0	.3	0	46	50	0	.....	.....	.17	.05	.000	Trace.	600	−
Do. [b]	Sept. 12, 1904	25	2 v.	<7	2.0	Trace.	64	62	Trace.	101	16	.204	.016	.000	.014	.....	.....
Do. [b]	.....do.....	25	2 v.	<7	2.1	Trace.	61	62	Trace.	82	.....	.216	.014	.000	.014	.....	.....
Do. [b]	Sept. 20, 1904	25	2 v.	<7	1.8	Trace.	57	62	Trace.	85	29	.206	.026	.000	.015	30 25	− +
St. Marys Lake at Eveleth [a]	Feb. 3, 1904	25	0	<7	.3	Trace.	16	34	.....	.....	.....	.35	.085	.000	Trace.	2	−
Do	May 12, 1904	29	0	<7	.3	0	12	17	0	.....	.....	.25	.05	.000	Trace.	21	−
Do. [b]	Sept. 12, 1904	18	1 v.	<7	.5	Trace.	26	21	0	58	12	.252	.014	.000	.010	.....	.....
Do. [b]	.....do.....	18	1 v.	<7	.5	Trace.	22	21	0	64	.....	.252	.016	.000	.010	.....	.....
Do. [b]	Sept. 20, 1904	4	1 v.	<7	.5	Trace.	19	21	0	43	16	.410	.032	.000	010	35 55	− −
Longyear Lake at Chisholm [a]	Nov. 26, 1903	324	2 v.	10	2.0	0	<10	49	.....	.....	.....	.....	.....	.....	.....	.....	−
Do	Feb. 1, 1904	324	4 v.	<7	2.0	0	8	29	.....	.....	.....	.45	.74	.000	.00	1,000	+
Do	May 13, 1904	224	2 v.	<7	.4	0	13	14	0	.....	.....	.60	.22	.000	Trace.	.....	+
Do. [b]	Sept. 19, 1904	224	2 v.	12	1.8	0	20	21	Trace.	87	30	.670	.130	.000	Trace.	250	−
Embarrass Lake at Biwabik [a]	Nov. 29, 1903	296	2 v.+1 M.	10	1.3	0	<6	32	.....	.....	.....	.22	.13	.000	.00	50	−
Do	Feb. 4, 1904	324	2 v.+2 M.	0	.3	0	24	48	.....	.....	.....	.60	.23	.000	Trace.	0	−
Do	May 11, 1904	224	3 v.	10	.4	0	26	36	0	.....	.....	.50	.09	.000	Trace.	550	−
Do. [b]	Sept. 19, 1904	176	3 v.	11	.6	0	27	28	0	95	3	.250	.034	.000	Trace.	50	−
St. Louis River above Cloquet [a]	Dec. 11, 1903	160	.....	10	1.0	0	46	62	.....	.....	.....	.26	.10	.000	Trace.	350	+
Do	Jan. 31, 1904	112	.....	<7	.3	Trace.	80	123	.....	.....	.....	.225	.081	.000	Trace.	.....	−
Do	May 16, 1904	240	3 v.	20	.3	0	23	28	0	.....	.....	.33	.02	.000	.00	550	−
Do. [b]	Oct. 31, 1904	292	2 v.	17	1.6	0	34	35	1.5	121	13	.502	.036	.000	.04	1,000	−
Do. [b]	Feb. 25, 1905	112	2 v.	<7	1.2	0	104	100	1.0	151	23	.322	.152	Trace.	.08	250	−
St. Louis River below Cloquet [a]	Jan. 31, 1904	112	.....	.....	.3	Trace.	82	94	.....	.....	.....	.262	.056	.000	Trace.	400	+
Do	May 16, 1904	260	2 v.+2 M.	20	.4	0	23	28	0	.....	.....	.26	.02	.000	.00	900	+
Do. [b]	Oct. 31, 1904	324	2 v.	20	1.8	0	33	35	3.0	128	21	.504	.026	.000	.04	900	+
Do. [b]	Feb. 25, 1905	112	2 v.	<7	1.4	0	96	96	1.0	146	13	.312	.072	Trace.	.08	600	+
St. Louis River at Scanlon [b]	Oct. 31, 1904	324	3 v.	19	1.8	0	31	35	3.0	121	16	.504	.036	.000	.04	1,200	+
Do	Feb. 25, 1905	112	2 v.	<7	1.8	0	98	97	1.0	156	22	.302	.032	Trace.	.08	500	−
St. Louis River average of 11 samples.	.....	196	2 v.	13	1.0	Trace.	59	66	1.3	137	18	.343	.057	Trace.	.04	.....	.....

[a] Determinations of chlorine and nitrogens by H. C. Carel; other tests by R. B. Dole.
[b] Analyses by R. B. Dole.
[c] Bacteriological examinations by Dr. E. H. Beckman.
[d] Estimated.

Most of the samples examined were collected from small lakes adjacent to the mining towns in the iron range. (See Pl. VI and Table 63.) Silver Lake, at Virginia, is a small, shallow body of water, which is connected at its upper end immediately with Virginia Lake and discharges by a small brook to Threemile Lake. Neither Silver Lake nor Virginia Lake exceeds one-half mile in diameter or 20 feet in depth, and both receive much infiltration from the city. They are used for log storage. They show high color and low chlorine, sulphuric acid, alkalinity, and total hardness. The albuminoid ammonia is fairly high and nitrites are generally present. *B. coli communis* was isolated in pure culture from every sample taken from these lakes. Samples were collected from Ely Lake at Sparta and at Eveleth. This body of water is considerably larger than either Silver or Virginia Lake. Though possibly as much lumber is floated in it, the effect of the logging operations is different because the volume of water is greater and the timber is stored for shorter periods. In this water the color and all of the dissolved constituents, including the nitrogenous matter, are low. *B. coli communis* was isolated in only one sample, though it might have been found if amounts larger than 1 cubic centimeter had been examined. St. Marys (or Virgin) Lake, about 3 miles from Eveleth, is a small deep body of water surrounded by woods. At the time samples were taken from this lake logging operations were not in progress on its shores and there were no logs in the water. As compared with the other lakes it is lower in color and in organic constituents, especially albuminoid ammonia. The water is very soft, has practically no turbidity, but sometimes has a slight vegetable odor. Its bacterial content is extremely low and *B. coli communis* was not isolated. Longyear Lake lies on the eastern border of Chisholm village. A sawmill is located on its eastern shore and the water is continually used for log storage. It has very high color and odor. It is low in mineral and other contents and is probably the softest water that was examined. *B. coli communis* was isolated from two samples. Embarrass Lake is an enlargement of Embarrass River, long, narrow, and shallow. It lies about three-quarters of a mile east of Biwabik, and is separated from it by a high ridge. Logs are driven on Embarrass River, and the lake generally contains a large number. The water is high in color and the albuminoid ammonia is usually excessive. It is soft and contains practically no sulphates, chlorine, or suspended matter. Its bacterial content is not particularly high and *B. coli communis* was not found.

St. Louis River was sampled (*a*) above all sources of pollution at Cloquet, (*b*) just above the paper mill below the village and (*c*) at Scanlon, 3 miles by river below Cloquet. Comparison of the three samples of each set shows almost identical organic content, and the slight

variations are quite as likely to be due to refuse from the sawmills at Cloquet or to normal fluctuations in the water as to pollution from the village. Five large sawmills stand along the river between the points at which the first and second samples were taken, but since the water is full of logs, which probably cause its high color, it is not possible to determine from the examinations whether the mills increase its organic content. *B. coli communis* was isolated once from water taken above Cloquet and in every sample but one taken below the village.

The waters of this basin are, in general, extremely soft. The dissolved minerals are principally small amounts of bicarbonates of calcium and magnesium. Sulphates and chlorides are present only in very small amounts. Table 63 gives an average of 11 examinations of St. Louis River near Cloquet, which shows the general quality of the discharge. It is especially noteworthy that Silver, Virginia, Longyear, and Embarrass lakes and St. Louis River at Cloquet, all of which contain great numbers of logs, show high color, and a vegetable odor; while, on the other hand, Ely and St. Marys lakes, which are not so much used by lumbering firms, show comparatively low color. It is possible that log extract is not the only source of the color, but it is fair to infer from the data at hand that it is the chief source. It should be mentioned in this connection that St. Louis basin below the Mesabi Range is largely swamp land, and the drainage from this area may be in part a cause of the color. Iron was found only in very small amounts. The test for iron was made by thoroughly oxidizing the sample with nitric acid and developing the potassio-ferric sulphocyanide. A qualitative examination of the sample taken from St. Louis River above Cloquet on October 31, 1904, was made to determine the nature of the coloring matter. Twenty-five hundred cubic centimeters of the sample were evaporated to dryness on the water bath and the residue was tested with various reagents. It consisted almost entirely of organic matter of vegetable origin, and the color of the dissolved residue was affected by change in the reaction from acid to alkaline or vice versa. It was apparently a solution of tannin and vegetable extractives.

St. Louis River at Cloquet shows the same seasonal variations that are exhibited by other rivers in the State. In winter the color, the turbidity, and the organic content are decreased, while the total residue, total hardness, and alkalinity are increased.

NOTES ON MUNICIPALITIES.

Four of the thirteen places in this basin have well-water supplies and four have lake-water supplies. Six municipalities report sanitary sewerage.

Biwabik, St. Louis County.—Near Embarrass Lake, which is connected with St. Louis River by Embarrass River. Water supply is

obtained from a well in the village, dug and timbered 9 feet by 9 feet square, extending through 100 feet of clay and 75 feet of sand and gravel. Ice supply is procured from Ely Lake at Sparta. No sewerage. Garbage is hauled to a public dump 1 mile from the village and burned as thoroughly as possible.

Carlton, Carlton County.—Near St. Louis River and below Cloquet. No waterworks or sewerage. Ice supply is cut from a mill pond on Otter Creek and from Chub Lake. Garbage is hauled to the village dumping ground and burned.

Chisholm, St. Louis County.—On Longyear Lake. A public water supply is installed; source of water not reported. Garbage is buried at the public dumping grounds.

Cloquet, Carlton County.—On St. Louis River a few miles below its confluence with Cloquet River. No public waterworks. Ice supply is cut from St. Louis River above the village. Sanitary sewerage discharges into St. Louis River. Garbage is hauled to dumping grounds away from the village and burned.

Duluth, St. Louis County.—At confluence of St. Louis Bay, the lower part of St. Louis River, with Lake Superior. Water supply is obtained unfiltered from Lake Superior, 8 miles east of the center of the city, by an intake which extends 1,500 feet into the lake and is 65 feet under water. Ice supply is obtained from Spirit Lake and from Lake Superior. Separate sanitary and storm sewerage systems discharge into Lake Superior. Garbage was formerly dumped on the bay front, but a modern crematory is now being installed. A State Normal School and large hospitals are located at Duluth.

Eveleth, St. Louis County.—On a small creek that enters Swan River, a tributary of the St. Louis. Water supply is taken unfiltered from Lake St. Marys (Virgin Lake), about 3 miles from the city. Ice supply is cut from Lakes Ely and St. Marys. A sanitary sewerage system discharges into the creek west of town, near Spruce Location. Garbage is regularly collected and hauled outside the city limits.

Hibbing, St. Louis County.—Drainage is carried by small creeks to Little Swan River. Water supply is obtained from an old prospecting shaft, 215 feet deep, passing through the following strata:

Log of well at Hibbing, St. Louis County.

	Feet.
Surface soil and gravel	6
Blue-clay hardpan	55
Quicksand	10
Hardpan	7
"Paint rock" and iron ore	127

Ice is shipped in from Lake Ely at Sparta. Sanitary sewerage discharges into Penobscot Creek 2 miles south of the city. Garbage is taken to a dumping ground outside of the city and burned.

McKinley, St. Louis County.—On the shore of a small lake connected with St. Louis River. Water supply is derived from driven wells, 5 inches in diameter by 40 feet deep, on the shore of the lake, passing through blue clay 9 feet and the rest in quicksand. The water is filtered through a chamber containing crushed rock, and provision is made for the use of alum coagulant if necessary. Ice supply is taken from the lake. No sewerage. Garbage is hauled to the village dumping ground.

Proctorknott (Proctor post-office), St. Louis County.—On Kingsbury Creek, which enters St. Louis Bay. No waterworks or sewerage. Ice supply cut from Kingsbury Creek.

Scanlon, Carlton County.—Three miles below Cloquet, on St. Louis River. No waterworks or sewerage. Ice is shipped in from Cloquet. Garbage is collected at regular intervals and deposited outside the village limits.

Sparta, St. Louis County.—On west shore of Lake Ely. Water supply is taken, unfiltered, from Lake Ely, which is at times, especially in the spring, exposed to local pollution. Ice supply is cut from Lake Ely. Considerable ice is sent from Sparta to neighboring cities and villages. No sewerage.

Two Harbors, Lake County.—On north shore of Lake Superior, 27 miles east of Duluth. Water supply is taken from Lake Superior without filtration, by a 20-inch intake pipe extending 620 feet into the lake, with inlet 56 feet under water. Ice supply is cut from Lake Superior. A combined storm and sanitary sewerage discharges into Agate Bay. Garbage is regularly removed to the public dumping grounds.

Virginia, St. Louis County.—On the shores of Virginia and Silver lakes. Water supply is obtained from a well on the shore of Silver Lake, with an emergency connection to Silver Lake. Consumers' ice is cut on St. Marys Lake. Ice for cold-storage purposes is cut on Silver Lake. Sewerage discharges into Threemile, or Mashkenoda, Lake.

RED RIVER BASIN.

GENERAL DESCRIPTION.

Boundaries.—Red River drainage area in Minnesota is bounded on the east by Rainy River area and by Mississippi basin, on the south by Minnesota River drainage area, on the west by the Dakotas, and on the north by Canada and minor tributaries of Red River. The river forms the boundary between North Dakota and Minnesota. (Pl. VII.)

This section treats essentially of that part of Red River drainage area which lies in Minnesota, but comprises also descriptions of the three principal North Dakota cities on Red River and a few inor-

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ganic analyses of water from western tributaries, procured from divers sources. Laboratory examinations were made of samples in Red River Valley as far north as Grand Forks, N. Dak., where Red Lake River joins the main stream. No samples were collected from tributaries in North Dakota and no field work was done in that State; consequently the conditions in the western half of the drainage area can be only briefly mentioned.

Character and slope of Red River.—Red River is formed[a] by the confluence of Ottertail and Bois de Sioux rivers at Breckenridge, whence it flows northward in an extremely tortuous course between North Dakota and Minnesota, through the province of Manitoba, into Lake Winnipeg. Its total length from Breckenridge to the Canadian boundary is 395.5[b] miles, though the distance between these points in a straight line is only about half that number of miles. Although the river is very crooked, it does not meander more than 4 or 5 miles to the right or left, but has many short ox-bow curves in its windings. It is a true prairie stream, having all the characteristics of rivers of that type. From Grand Forks to the border it is navigated by flatboats and scows carrying grain and other produce. Red Lake River, the chief tributary, is navigable from Thief River Falls to and across Red Lake. With these exceptions, the streams of this region are not generally used for shipping, either on account of shallow water or the presence of rapids.

Red River is extremely sluggish, its slope rarely exceeding 6 inches per mile.[c] From Breckenridge to Moorhead, which are 41 miles apart in a direct line, the stream runs 97 miles and has a total fall of 74 feet, 34 feet of which occur in a stretch of 21 miles, leaving the average slope of the remainder only 0.5 foot per mile. From Moorhead to Grand Forks, 155 miles, there is generally a slight slope, except at Goose Rapids, where a fall of 13 feet occurs in a little over 13 miles. In the 143.5 miles from Grand Forks to the Canadian border the river has an average slope of about 0.24 foot per mile. From Breckenridge to the international boundary its total fall is 180 feet, and its average slope in the United States is 0.46 foot per mile.

Tributaries of Red River.—Of the two streams that unite to form Red River the Ottertail furnishes 90 per cent of the stream flow. It rises in the southwest part of Clearwater County on the western slope of the Leaf Hills and flows southward to Fergus Falls, passing through or uniting with a great number of lakes scattered over Becker and Ottertail counties, the principal of which are Height of Land, Pine,

[a] Decision of the United States Geographic Board.
[b] Ann. Rept. Chief of Engineers, U. S. Army, for 1904, pt. 1, p. 427.
[c] Ann. Rept. Chief of Engineers, U. S. Army, for 1875, pt. 1, p. 370.
Ibid. for 1904, pt. 1, p. 427.
Gannett, Henry, Profiles of rivers in the United States: Water-Sup. and Irr. Paper No. 44, U. S. Geol. Survey.

Rush, and Ottertail lakes. After its confluence with the chief tri-tary, Pelican River, 4 miles below Fergus Falls, it follows a weste course to its mouth. From Ottertail Lake to Breckenridge its to fall is 368 feet, nearly all of which occurs in the hilly country above near Fergus Falls, the river in its lower portion being sluggish a flowing in a tortuous course. Bois de Sioux River is a small, me dering stream, nearly dry in summer, forming part of the bound between the Dakotas and Minnesota; Lake Traverse, its headwat is a long, narrow body similar to Big Stone Lake, which lies south it and from the basin of which it is separated by a low, narrow s of land. Lake Traverse is 1 to 1½ miles wide and 15 miles long, its average depth is 10 feet. It stretches northeast and southwest a deep valley, which it fills from bluff to bluff. At its marshy nor ern extremity the high banks gradually recede and Bois de Si River flows from it 35 miles northward to Breckenridge. The ri has a total fall of 21 feet. Red Lake River is the outlet of Red La in the central part of Beltrami County. This body of water, the la est lake that is included entirely within the State, is divided into t parts by a long cape extending from the east side. The southwest portion is slightly larger than the other and is the source of the ri The lake is shallow and is surrounded by marshy woodland. Fr Red Lake the river runs westward 50 miles to its junction with Th River at Thief River Falls. This upper portion of the stream i navigable, and regular water communication is maintained duri the open season between Thief River Falls and the small settle ments on Red Lake. In its southwestern course to Crookston th river traverses several falls and rapids, so that it is not there navig ble. Below Crookston it winds westward again as a sluggish prair stream to its confluence with Red River at Grand Forks, N. Dak Its total fall from Red Lake to Grand Forks is probably not less than 400 feet.[b] Other smaller tributaries of Red River are Wild Rice Sand Hill, Snake, and Two Rivers in Minnesota, and Pembina, Cheyenne, and Wild Rice rivers in North Dakota.

Topography.—The basin consists of two sections—a central, rolling prairie and a surrounding hilly country, which is also prairie land but rather more undulating than the lower part. The eastern or hilly part of the basin is forested and contains many lakes; the lower or prairie portion along the main stream comprises many swamps, as well as sites of swamps that have been drained by ditches.

Geology.—Since the entire basin of Red River in Minnesota is covered with thick glacial deposits, nearly all information regarding the

[a] Though Red Lake is commonly regarded as the source of Red Lake River, that name is also applied to the largest tributary of Red Lake, which rises in Lake Julia, in Nebish township, Beltrami County, about 20 miles south of Red Lake.

[b] Water Powers of the United States, pt. 2, sec. 1, p. 90, Tenth Census U. S.

underlying rocks must be derived from an examination of well borings. Fortunately a large number of deep wells have been bored all over the area, and from the records of these borings considerable data concerning the geology of the section have been obtained. The older formations throughout the greater part of the basin are covered by Cretaceous rocks, upon which rests a heavy mantle of Pleistocene deposits. The older rocks have, however, practically no influence on the quality of surface waters in the valley of Red River. The Cretaceous rocks, on the other hand, through their alkaline contents, have an important influence. The stratified materials of this system in Red River Valley have been described in full by Prof. Warren Upham.[a] The earliest deposits, termed the Dakota formation, consist of yellow, red, and white sandstone, with occasional shales and impure lignites. They furnish a strong artesian flow in many parts of the area. Next in order of time are the beds of the Benton formation, consisting of shales and clays, alternating in some places with layers of soft limestone. Above these lie the calcareous marls of the Niobrara and the darker colored shales and clays of the Pierre. The latter three are extensive and generally encountered by well borings sunk throughout the valley. All of these rocks are strongly impregnated with alkaline and alkaline-earth compounds.

The unmodified drift, from 100 to 200 feet thick, consists mainly of hard blue till, which becomes softer and has a yellow color near the surface. Since all this material is largely derived from the disintegration of the Cretaceous deposits, it is, like them, strong in hardening constituents, and on account of its comparatively loose packing is more easily dissolved by the waters with which it comes in contact. Water drawn from wells in the old drift is strongly alkaline and often brackish and unpalatable.

In the latter part of the Pleistocene epoch Lake Agassiz covered the greater part of Red River basin. This immense lake found outlet southward, through the valley now occupied by Traverse and Big Stone lakes and Minnesota River. The traces of its existence consist of the beaches it left in its gradual recession, the broad, deep valley that formed its outlet, and the fine, lacustrine silts which make Red River Valley one of the most fertile regions in the world.

Soil and subsoil.—The characteristic influence of the Cretaceous rocks on the upper layers of the drift is demonstrated by an examination of Table 64, which gives the average composition of the soil and subsoil in Red River Valley and in the entire State. This table shows how greatly the soil here differs from the soils in other parts of the State, and especially from the nonsoluble soils of the St. Croix Valley.

[a] The Glacial Lake Agassiz: Mon. U. S. Geol. Survey, vol. 25, pp. 81-107.

TABLE 64.—*Chemical composition of soil and subsoil in Red River basin.*

Constituent.	Surface soil.		Subsoil.		Surface soil.			
	Red River basin.	Entire State.[a]	Red River basin.	Entire State.[a]	Marsh.	Swamp.	Peat.	Alkali.
Insoluble in HCl	70.52	79.92	65.93	82.41	19.70	14.33	12.60	67.05
Volatile	10.43	8.98	5.51	5.33	27.72	27.72	52.60	6.57
Potassium oxide (K_2O)	.55	.43	.45	.40	.44	.44	.40	.46
Sodium oxide (Na_2O)	.49	.45	.37	.32	.30	.30	.21	2.56
Calcium oxide (CaO)	2.18	1.29	5.67	1.78	23.27	23.31	12.20	7.48
Magnesium oxide (MgO)	.89	.61	1.52	.80	.80	.80	.64	.16
Oxides of iron and aluminum (Fe_2O_3+Al_2O_3)	10.59	7.20	10.41	8.32	3.25	3.25	2.02	9.04
Phosphoric anhydride (P_2O_5)	.26	.20	.18	.17	.30	.30	.21	.27
Sulphuric anhydride (SO_3)	.27	.10	.08	.06	.75	.75	.22	1.00
Carbonic anhydride (CO_2)	1.78	.62	5.72	.93	23.00	23.00	12.60	4.84

[a] Snyder, H., Characteristic features of Minnesota soils and conservation of fertility: Bull. 65, Agr. Exp. Sta., University of Minnesota, Chem. Div., Nov., 1899, p. 69.

The amount of soluble material is much greater than the average for the State, while the quantity of volatile matter is slightly less. All other constituents are much higher, especially calcium, magnesium, sodium, and potassium. It is evident that there are considerable amounts of alkaline carbonates, which produce a corresponding hardness in the drainage waters. The analyses given in the last four columns show the characteristic composition of different types of surface soil. The marshes are found to be very high in volatile and soluble constituents, especially in calcium, possibly on account of marl deposits. The peaty soils contain over 50 per cent of volatile matter, and, they too, indicate the presence of much calcium carbonate. True alkali soils are found in many places where the surface of the ground is covered with a white efflorescence due to the deposition of alkaline salts by evaporation. Such soils are naturally high in soluble matter, particularly sodium. Just as the Cretaceous formations have influenced the chemical constitution of the drift, the drift has in turn produced an alkaline soil, which imparts its essential qualities to the lakes and streams that stand or flow over it. The waters examined in this valley show a far greater percentage of dissolved minerals than those in any other part of the State.

INDUSTRIAL POLLUTION.

Only a few manufacturing establishments are located in Red River basin, and these furnish little waste of undesirable character. They are tabulated below.

TABLE 65.—*Industrial establishments causing stream pollution in Red River basin.*

Breweries	4
Sawmills	9
Tanneries	2
Woolen mills	3

Nearly all of the sawmills are on Red Lake River at or above Crookston. The color of the stream may be, to some extent, affected by the logging operations or the wastes from the mills.

MUNICIPAL POLLUTION.

Since Red River basin is devoted principally to lumbering and to wheat raising it is thinly populated, and the size of its towns or cities is determined not by the development of manufacturing interests, but by the necessity for trading centers. The following tables show the distribution of population for three successive censuses:

TABLE 66.—*Population in Red River basin in Minnesota.*

County.	1890.	1900.	1905.
Becker	6,771	10,603	13,425
Beltrami	100	2,949	3,504
Bigstone	508	856	1,032
Clay	11,517	17,942	19,457
Clearwater	(a)	(a)	4,830
Grant	3,437	4,467	4,826
Itasca	100	753	2,795
Kittson	5,387	7,889	9,878
Marshall	9,130	15,689	17,737
Norman	10,618	15,045	18,176
Ottertail	20,661	28,071	29,994
Polk	30,192	35,429	37,212
Red Lake	(b)	12,195	15,955
Roseau	(c)	5,596	8,952
Stevens	797	1,355	1,442
Traverse	4,018	6,852	7,083
Red Lake Indian Reservation	(d)	(d)	1,327
White Earth Indian Reservation	(d)	(d)	4,968
Total population	107,382	173,771	211,872

a Formed from part of Beltrami County in 1903.
b Formed from part of Polk County in 1897.
c No population given for 1890.
d Included in county population.

TABLE 67.—*Density of population in Red River basin.*

Area considered.	Drainage area in square miles.	Population per square mile.		
		1890.	1900.	1905.
Red Lake River basin, above Crookston:				
Entire area	a 5,525	1.9	4.3	6.7
Excluding chief settlements		1.8	3.6	5.8
Red Lake River basin, above mouth:				
Entire area	a 6,100	3.8	7.8	10.2
Excluding chief settlements		2.0	6.3	8.2
Ottertail River basin, above Fergus Falls:				
Entire area	a 1,311	10.5	14.7	16.6
Excluding chief settlements		10.0	13.1	14.6
Ottertail River basin, above mouth:				
Entire area	a 2,300	11.1	15.7	17.3
Excluding chief settlements		8.4	10.8	11.9
Red River basin in Minnesota, above Moorhead:				
Entire area	a 3,800	10.2	15.2	18.0
Excluding chief settlements		6.6	11.6	13.9
Red River basin in Minnesota, above Red Lake:				
Entire area	a 7,800	9.3	13.9	16.6
Excluding chief settlements		7.8	11.3	13.6
Red River basin in Minnesota:				
Entire area	b 18,365	5.9	9.4	11.5
Excluding chief settlements		4.9	7.7	9.4

a Measured from best available maps.
b Hall, C. W., Geography and Geology of Minnesota, vol. I, p. 151, Minneapolis, 1903.

The population of the basin is less than half as dense as the average for the State as a whole. Though statistics show that the population is rapidly increasing, it is doubtful whether Red River Valley will ever become as thickly settled as some regions of the State where manufacturing interests are more predominant, for this is essentially a farming and lumbering district. Its most thickly settled part lies between Moorhead and Lake Traverse, particularly in the basin of Ottertail River. The population is most sparse in Red Lake River basin above Crookston. The low population per square mile is counterbalanced, however, so far as stream pollution is concerned, by the fact that the cities and villages are situated directly on the banks of streams into which they discharge sewage and other refuse. Since a great many of these settlements are supplied with unfiltered surface water for general municipal consumption, it is particularly important to consider in detail the chance of river pollution from farms and villages on the watershed. (See Pl. VII.)

TABLE 68.—*Chief settlements in Red River basin, above Breckenridge.*

Locality.	Distance above Breckenridge, in miles.	Population.		
		1890.	1900.	1905.
Detroit	90	1,510	2,060	2,149
Fergus Falls	40	3,772	6,072	6,692
Frazee	110	.....	1,000	1,146
Pelican Rapids	60	624	1,033	1,095
Perham	90	761	1,182	1,366
Total	.....	6,667	11,347	12,448

TABLE 69.—*Chief settlements in Red River basin, above Moorhead.*

Locality.	Distance above Moorhead, in miles.	Population.		
		1890.	1900.	1905.
Settlements above Breckenridge (see Table 68)	.....	6,667	11,347	12,448
Wahpeton, N. Dak	97	1,510	2,228	[a] 2,500
Wheaton	150	388	1,132	1,346
Total	.....	9,215	15,989	18,144

TABLE 70.—*Chief settlements in Red River basin, above Grand Forks.*

Locality.	Distance above Grand Forks, in miles.	Population.		
		1890.	1900.	1905.
Settlements above Moorhead (see Table 69)	.....	9,215	15,989	18,144
Ada	100	622	1,253	1,515
Barnesville	170	1,069	1,326	1,566
Fargo, N. Dak	155	5,664	9,589	[a] 12,000
Moorhead	155	2,088	3,730	4,794
Total	.....	18,658	31,887	38,019

[a] Estimated.

Table 67 gives the number of inhabitants per square mile above each of the principal cities. Tables 68 to 70 give the principal sources of municipal pollution. In view of the fact that the lesser drainage basins have the same characteristics with a few exceptions, observations on one may be applied as well to the others. The statistics show sources of pollution above every city that uses raw stream water as a public supply. It is also evident from a consideration of gage heights that at certain periods of the year much objectionable, if not dangerous, matter is in the streams, and is transported by them to the vicinity of all the waterworks intakes. Above Fergus Falls, on Ottertail River, there is considerable rural population and immediately above the city intake there are several likely sources of contamination. Fergus Falls itself furnishes too much pollution from its sewers and from the State insane asylum, near by, to permit the use of unfiltered river water at Breckenridge. Fargo and Moorhead, on Red River, are using a water that is objectionable on account of its turbidity, and is besides liable to sewagic pollution not only by settlements above but by the suburbs of the cities themselves. Much of the territory above Crookston, in Red Lake River basin, is timbered and the reservations have not yet been entirely opened for settlement; consequently the population per square mile is low. Three sawmill villages—Thief River Falls, Red Lake Falls, and St. Hilaire—are located on the river above Crookston. The principal source of pollution of Red Lake River above East Grand Forks is Crookston, which discharges sewage into the river. The supply of Grand Forks, N. Dak., is taken from Red Lake at its entrance into Red River. There can be no doubt that Red River, receiving as it does the sewage of Fargo, Moorhead, and Breckenridge, is the more seriously polluted stream of the two. It is also evident that the water of Red Lake River in its unfiltered condition is not safe for drinking or for general domestic use. Whether the sewage from the above-mentioned cities always reaches Grand Forks is a debatable question, not to be decided by a consideration of the distance traveled alone, but by a determination whether the pathogenic bacteria perish during the time consumed in the voyage. Unfortunately, the average stream velocities can not be determined by the data at hand. Ordinarily Red River is sluggish, shallow, and winding. During flood times it is subject to rapid and extreme rises, which sweep the bed free from accumulated organic matter and greatly increase the velocity of the current. Red River carries at all times an amount of suspended matter that would make it undesirable for use without filtration.

The Red River system drains about half of North Dakota along the broad prairie in that part of the State bordering Minnesota east

of the Dakota foothills. The valley is devoted almost exclusively wheat raising, containing within its borders some of the largest far in the world. The population is sparse, and there are few lar cities. Three of the largest—Grand Forks, Fargo, and Wahpeton are on the banks of Red River. (See Pl. V.) The North Dako tributaries of Red River are generally small, meandering, and sl gish. Many of them are dry in summer.

QUALITY OF WATER.

The location of sampling stations in Red River basin is shown i Pl. I. They were selected above and below the principal settlemen with the view (*a*) of determining how much evidence of pollutio from infiltration or from direct discharge of sewage could be gain by laboratory examinations; (*b*) of estimating by rapid and approxi mate methods the amount of mineral matter ordinarily carried b the streams; and (*c*) of finding the seasonal variation in the chemic and bacteriological conditions of the water. Two complete sets o samples were taken, one late in the fall of 1904, just before the strea closed, the other in the latter part of March, 1905, while the ice w going out and the streams were rising in flood. In addition so miscellaneous samples were taken at Crookston and at Grand Forks Table 71 gives the results of analyses.

It is commonly believed that the entrance of sewage into water may be detected in analyses by changes in the figures representing certain arbitrary estimates. The amounts of chlorine, free ammonia, and albuminoid ammonia are supposed to increase; nitrites, representing organic matter in an unstable condition of oxidation, are regarded a indicating pollution; the amount of nitrates is considered to represen the completeness of the destruction of the organic material; finally an increase in bacterial count is expected, together with the presenc of *B. coli communis*, an intestinal organism always present in fres feces. The chemical analyses made fail to reveal positive evidenc that any of the unquestionable sources of dangerous pollution dam age the stream waters, either because the contaminating substance were much diluted or because the samples did not happen to strik currents of pollution in the rivers. The points for analysis were however, chosen with the definite object of getting representativ samples both above and below each city, and the stations were suc as would generally be selected by chemists engaged in similar work Though some of the analyses indicate slight increases in the figure representing organic matter, yet the changes noted were only such a might be due to normal fluctuations in quality, independent of th introduction of sewage. From this point of view the chemical resul are unsatisfactory.

[Parts per million.]

Locality and source.	Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Total alkalinity.	Total hardness.	Iron.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Bacteria per c. c.[a]	B. coli communis.[a]
Red Lake River:																	
Above Crookston[b]	Dec. 16, 1903				6.4			173				0.42	0.21	0.00	Trace.	500	+
Below Crookston[b]	do			12		0	153									1,000	+
Above Crookston[b]	Jan. 27, 1904	25	0	<7	.3			206				.37	.085	.00	Trace.	350	+
Below Crookston[b]	do	25	0	12	.4	Trace.	164	164				.41	.09	.00	Trace.	900	+
Above Thief River[c]	Nov. 22, 1904	18	0	17	.3	Trace.	144	166	Trace.	210	14	.740	.034	Trace.	.03	800	−
Below Thief River[c]	do	18	0	17	.5	Trace.	146	166	Trace.	220	15	.770	.036	Trace.	.03	1,300	−
Above Crookston[c]	do	12	0	25	.4	Trace.	149	166	Trace.	232	18	.550	.044	.000	.03	1,400	+
Below Crookston[c]	do	12	0	25	.4	Trace.	141	166	Trace.	231	16	.650	.044	.000	.03	2,100	+
At mouth[c]	Nov. 21, 1904	18		40	.9	[d] 5	185	251	2.0	280	58	.530	.062	.000	.02	1,600	+
Above Thief River[c]	Mar. 31, 1905	18	2 v.	9	1.0	[d] 5	131	129	Trace.			.460	.062	.000	.04	4,100	−
Below Thief River[c]	do	18	2 v.	10	1.2	[d] 5	132	129	Trace.			.460	.066	.000	.04	2,700	+
Above Crookston[c]	do	25	2 v.	15	1.7	[d] 10	139	149	Trace.			.476	.058	.000		4,700	+
Below Crookston[c]	do	25	1 v.	30	1.7	[d] 10	142	142	Trace.			.476	.072	.000		10,500	+
At mouth[c]	do	25	3 v.	50	1.7	[d] 20	145	136	1.5	235	54	.488	.042	Trace.	.06	7,700	+
At mouth[c]	May 25, 1905	60	3 v.	250	1.1	[d] 15	178	199	Trace.			.570	.134	.000	.04	1,100	+
Ottertail River:																	
Above Fergus Falls[c]	Nov. 18, 1904	4	0	<7	1.0	Trace.	182	209	0	214	8	.248	.020	.000	.02	500	−
Below Fergus Falls[c]	do	4	1M.	<7	1.8	Trace.	181	209	0	213	9	.260	.026	.000	.02	1,500	+
At Breckenridge[c]	Nov. 19, 1904	4		20	1.6	[d] 5	197	209	2.5	343	26	.414	.060	.000		1,100	+
Above Fergus Falls[c]	Mar. 28, 1905	4	0	<7	1.9	[d] 5	196	183	.5	222	25	.330	.058	.000	.08	375	−
Below Fergus Falls[c]	do	4	1 m.	<7	2.2	[d] 5	193	180	.5	219	24	.350	.110	.000	.08	2,600	+
At Breckenridge[c]	Mar. 29, 1905	4	2 e.	100	2.2	[d] 5	194	183	2.6	518	32	.660	.172	.002	.07	3,300	+
Traverse Lake at Browns Valley[c]	Dec. 4, 1904	0		10	26.0	432	216	696	Trace.	1,477	517	.860	.182	.004	.04	4,700	−
Bois de Sioux River at Breckenridge[c]	Nov. 19, 1904	60		<7	2.2	442	314	640	Trace.	1,181	340	1.20	.074	.000	.05	2,900	+
Sand Hill River at Beltrami[c]	Nov. 23, 1904	4	0	15	.3	[d] 5	278	304		315	17	.270	.150	Trace.	.05	1,300	+
State Ditch at Ada[c]	do	18	2 e.	50	.8	[d] 15	247	277	1.0	324	20	.320	.028	.000	.01	1,300	−
Traverse Lake at Browns Valley[c]	Mar. 19, 1905	4	2 v+1 m.	11	13.0	359	112	382	1.5	686	229	.492	.042	.000	.04	4,700	−
Bois de Sioux River at Breckenridge[c]	Mar. 29, 1905	29	3 m.	<7	8.2	185	121	245	Trace.	428	137	.502	.182	.000	.02	1,900	−
Red River:																	
Above Moorhead[c]	Nov. 20, 1904	12		26	7.7	35	209	333	1.0	309	36	.410	.070	Trace.	.00	650	+
Above Red Lake River[c]	Nov. 21, 1904	12		50	9.2	50	242	333	1.0	419	65	.284	.046	.000	.00	800	+
Below Red Lake River[c]	do	18		50	7.2	29	217	333	1.5	341	47	.368	.052	.000	Trace.	3,200	+
At Breckenridge[c]	Mar. 29, 1905	4	2 e.	90	2.6	[d] 5	192	186	Trace.	406	20	.522	.158	.002	.07	2,300	+
Above Moorhead[c]	do	4	3 e.	70	2.8	[d] 10	172	177	Trace.	291	54	.356	.046	.002	.05	3,700	+
Above Red Lake River[c]	Mar. 30, 1905	4	3 e.	65	9.5	47	200	208	2.0	358	88	.376	.038	Trace.	.07	5,800	−
Below Red Lake River[c]	do	18	3 e+1 M.	60	7.5	37	195	182	Trace.	302	74	.396	.056	Trace.	.07	11,000	+
Above Red Lake River[c]	May 25, 1905	60	2 v+2 M.	550	5.9	81	202	268	Trace.			.570	.060	Trace.	.05	1,600	+
Below Red Lake River[c]	do	60	2 v+2 M.	400	4.8	50	194	243	Trace.			.570	.060	Trace.	.05	2,200	+

[a] Bacteriological examinations by Dr. E. H. Beckman.
[b] Determinations of chlorine and nitrogens by H. C. Carel; other determinations by R. B. Dole.
[c] Analyses by R. B. Dole.
[d] Estimated.

The bacteriological examinations yield much more satisfactory evidences of pollution. Water taken from Red Lake River above Thief River, after flowing through a practically uninhabited country, does not show the presence of *B. coli communis*. In all other samples of water from Red Lake River the organism was found. It is worthy of note that it was isolated from 1 cubic centimeter amounts of every sample taken above the intake of the Crookston waterworks. It was not found in samples of Ottertail River taken above Fergus Falls, but, except in one or two other samples, it was found in the waters of all the rivers of the area.

Red River and most of its tributaries show higher mineral content than the other streams in the State, due to solution of the alkaline materials constantly present in the soil and subsoil. The water of Lake Traverse, at the head of Bois de Sioux River, shows the highest percentage of total and soluble solids, total hardness, sulphuric acid, and chlorine, indicating that it is very strongly charged with alkaline salts. This alkalinity is probably caused by the inflow of springs that have percolated through the calcareous alkaline strata of the bluffs that rise abruptly on both shores. The stream that forms its outlet, Bois de Sioux River, is similarly mineralized. Ottertail River, at Fergus Falls, is low in chlorine, sulphuric acid, turbidity, and color, but has considerable alkalinity and total hardness. The percentage of solids soluble in alcohol is noticeable here, as in general throughout the Red River basin, indicating the probable presence of alkaline salts. There is little change in these constituents at Breckenridge except the increase in turbidity, which causes a corresponding change in total solids. In its northward course from Breckenridge Red River is joined by a large number of short streams that drain swamps or the alkaline soils of the valley near the main river, and the effect of this added drainage is shown by comparison of analyses of the water of Red River at Breckenridge, Moorhead, and above Red Lake River at Grand Forks. The comparatively high chlorine in Red River is undoubtedly due to soluble chlorides derived from the soils and not to sewagic pollution. Therefore this figure gives no index of the sanitary condition of the water. The turbidity is generally high and the color low. The odor is extremely variable. The amount of sulphuric acid is high as compared with that in Mississippi River. The water of Red River is similar in many respects to that of Minnesota River. Iron is always found. The total residue in the water of Red River is higher than that found in any other stream examined, and the percentage of solids soluble in alcohol is noticeable.

[Parts per million.]

Locality.	Source.	Date.	Suspended matter.	Silica (SiO_2).	Oxides of iron and aluminum ($Fe_2O_3 + Al_2O_3$).	Calcium (Ca).	Magnesium (Mg).	Sodium (Na).	Chlorine (Cl).	Sulphate radicle (SO_4).	Carbonate radicle (CO_3).	Total solids.
Bathgate, N. Dak	Tongue River	Mar. 5, 1904 [a]	6.8	29	3.4	100	25	23	12	31	212	.....
Crookston, Minn	Red Lake River	Mar. 31, 1903 [a]	18	4.4	2.5	56	17	2.3	5.9	15	111	.....
Drayton, N. Dak	Red River	....do	31	14	1	56	20	11	18	26	118	.....
Eastedge, N. Dak	Sheyenne River	Mar. 26, 1903 [a]	.....	18	Trace.	70	29	43	18	141	130	.....
East Grand Forks, Minn	Red Lake River	Mar. 31, 1903 [a]	18	3.7	3.9	50	14	1.3	4.2	12	103	.....
Fargo, N. Dak	Red River	Feb. 12, 1903 [a]	.....	.....	11	82	18	22	2.8	29	175	.....
Do	....do	Jan. 15, 1891 [b]	.....	8.9	2.5	67	37	1.9	6.1	26	158	341
Fergus Falls, Minn	Ottertail River	Apr. 14, 1903 [a]	3.9	9.9	Trace.	35	23	13	6	5	118.1	.....
Do	....do	June, 1882 [c]	.....	14	1.2	40	20	4	1.3	1.2	117	[d] 202
Forest River, N. Dak	Forest River	Mar. 31, 1903 [a]	3.7	11	16	116	35	25	12	118	208	.....
Graceville, Minn	Lake	Nov 14, 1888 [b]	.....	.....	49	57	59	58	8.5	186	185	605
Hannaford, N. Dak	Hill Creek	Feb. 24, 1903 [a]	4.9	21	Trace.	128	38	37	18	188	203	.....
Jessie, N. Dak	Pond	....do	8	17	10	54	80	339	115	381	383	.....
Leeds, N. Dak	....do	Mar. 26, 1903 [a]	12	27	20	82	30	76	18	45	254	.....
Lisbon, N. Dak	Sheyenne River	Feb. 12, 1903 [a]	2	14	3.4	103	56	124	36	295	237	.....
Magnolia, N. Dak	Pond	Feb. 24, 1903 [a]	11	15	3.	108	75	77	12	354	214	.....
Mapleton, N. Dak	Maple River	Feb. 12, 1903 [a]	12	27	5.9	233	114	124	73	547	390	.....
Mekinock, N. Dak	Turtle River	Mar. 31, 1903 [a]	.....	28	2.	120	34	46	42	158	186	.....
Pembina, N. Dak	Pembina River	....do	8.9	7	1.5	60	20	21	18	36	130	.....
Ralph, Minn	Brook	Aug. 29, 1901 [b]	.....	.....	1.5	38	14	8.7	1.3	4.8	100	171
Stockwood, Minn	Buffalo River	Mar. 31, 1903 [a]	9.9	24	2	88	36	17	12	68	192	.....
St. Vincent, Minn	Red River	June 10, 1882 [c]	.....	13	1.	49	24	16	14	46	117	[e] 284
Wahpeton, N. Dak	Ottertail River	Apr 17, 1903 [a]	2	20	Trace.	34	25	11	6	14	113	.....
Wheaton, Minn	Mustinka River	Aug. 13, 1903 [b]	.....	.....	.....	95	60	52	4	328	146	688
Wild Rice, N. Dak	Wild Rice River	Oct. 17, 1888 [b]	.....	.....	10	78	42	117	41	219	203	712
Winnipeg, Minn	Buffalo River	Apr. 31, 1903 [a]	5.9	12	Trace.	71	33	5.4	6	51	157	.....
Valley City, N. Dak	Sheyenne River	Feb. 12, 1903 [a]	.....	16	7.5	91	52.3	105	30	188	289	.....

[a] Analysis furnished by Kennicott Water Softener Company.
[b] Analysis furnished by Chicago, Milwaukee and St. Paul Railway.
[c] Analysis by W. A. Noyes.
[d] Traces of nitrates, nitrites, bromides, and lithium; potassium=2.4.
[e] Traces of nitrites and bromides. Nitrites=0.83; phosphate radicle=0.49; lithium=0.11; potassium=3.9

The water of Red Lake River resembles in many respects that of upper Mississippi River. It is low in turbidity and sulphuric acid and has moderate alkalinity, total hardness, and total residue, while it carries some color and generally has a vegetable odor. It is somewhat similar to that of Ottertail River above Fergus Falls. The differences between the waters of upper Red Lake and Ottertail rivers and that of Red River lead to the inference that forest lands have considerable influence on the quality of stream water, perhaps because forest soils are less easily disintegrated and not subject to the excessive leaching that occurs in prairie regions. It is at any rate worthy of note that the waters of Red River basin that come from forested areas are softer and apparently contain less alkali than those that come from the prairies.

Red River and Red Lake River unite at Grand Forks. A comparison of the three samples taken in that vicinity, namely, above and below Red Lake River on Red River, and above Red River on Red Lake River, show the effect of diluting Red River with a softer water. The turbidity, chlorine, sulphuric acid, alkalinity, total hardness, and total residue are decreased, while the color is often increased. The organic content of Red Lake River at this point, as shown by the nitrogen determinations, is higher than that of Red River.

In conclusion, a table is given showing the average condition of Red River as compared with upper Mississippi and Minnesota rivers. It is distinctly different from the former and conforms in quality in many respects with the latter.

TABLE 73.—*Summary of quality of water.*

[Parts per million.]

Determination.	Red River.	Minnesota River.	Upper Mississippi River.
Color	21	30	50
Odor			2 v.
Turbidity	151	70	<7
Chlorine	6.3	6.4	.9
Sulphate radicle	38	178	Trace.
Total alkalinity	202	220	151
Total hardness	251	470	136
Iron	Trace.	Trace.	Trace.
Total residue	346	556	189
Soluble residue	54	143	16
Albuminoid ammonia	0.428	0.454	0.475
Free ammonia	0.065	0.193	0.191
Nitrites	Trace.	0.009	0.000
Nitrates	0.03	0.16	0.05

NOTES ON MUNICIPALITIES.

Twenty-five Minnesota settlements are reported in Red River basin. Eleven are supplied with ground water, five with surface water, and six are equipped with sanitary sewerage.

Ada, Norman County.—On Marsh River, which is at this point connected with Wild Rice River by a ditch. Water supply is obtained from two 2-inch tubular wells, 265 feet deep, driven through clay to water-bearing sand. Sewerage system discharges into Marsh River. Ice supply is cut from "Long Lake," a part of the ditch joining the two rivers. Garbage is hauled to a dumping ground outside the village.

Argyle, Marshall County.—On Middle River, 10 miles above its entrance into Snake River. No waterworks or sewerage. Ice supply is cut from Middle River. Some garbage is fed to hogs and the remainder is taken to the village dumping grounds.

Audubon, Becker County.—On Audubon Lake. No waterworks or sewerage. Ice supply is cut from Audubon Lake and other small lakes in the vicinity.

Barnesville, Clay County.—On south branch of Buffalo River. No waterworks or sewerage system. Ice supply is cut from a pond formed by damming a neighboring creek. Garbage is burned or hauled away at intervals.

Black Duck, Beltrami County.—On Black Duck River at the outlet of Black Duck Lake. Water supply for fire protection is taken from two 4-inch wells about 90 feet deep in the drift. Ice supply is cut from a small lake near the village. No sewerage. Garbage is hauled to the village dumping ground.

Breckenridge, Wilkin County.—At point where Ottertail and Bois de Sioux rivers unite to form Red River. Water supply is taken without filtration from Ottertail River near the upper edge of the town. Ice supply is cut from Ottertail River. A combined sewerage system discharges into Ottertail River. Garbage is carted to the village dump.

Crookston, Polk County.—On Red Lake River 50 miles above its entrance into Red River. Water supply is taken unfiltered from Red Lake River 1 mile above the center of the city. Deep-well water is also furnished by a separate system over a limited area. Ice supply is cut from Red Lake River. A combined storm and sanitary sewerage discharges into Red Lake River below the city. Garbage is removed to the village dumping ground and burned.

Detroit, Becker County.—On Pelican River near Detroit Lake. Water supply is obtained from a shallow well dug in sand. Ice supply is cut from Detroit Lake. No sewerage. Garbage is removed to the municipal dumping ground.

East Grand Forks, Polk County.—On Red Lake River at its confluence with Red River opposite Grand Forks, N. Dak. A system of waterworks is under construction. Part of the village is at present supplied from the public system of Grand Forks. Ice supply is cut

from Red River, from Red Lake River, and from Maple Lake. Garbage is irregularly hauled outside the village limits.

Fargo, Cass County, N. Dak.—Opposite Moorhead, on Red River. Water supply is taken from Red River without filtration. Ice supply is cut from Red River. The combined sewerage system empties into the same body of water.

Fergus Falls, Ottertail County.—On Ottertail River 40 miles above its confluence with Bois de Sioux River. Water supply is taken unfiltered from Ottertail River at a point 1 mile above the center of the city. Ice supply is cut from Ottertail River. A combined sewerage system discharges into Ottertail River. Some garbage is hauled from the city and some is used for grading. The Third State Hospital for the Insane, 1,500 inmates, is situated about 1 mile north of the center of the city. The hospital is at present supplied with city water and is connected with the city sewers.

Fertile, Polk County.—On Sand Hill River 30 miles below Fosston. Water supply is obtained from a 6-inch well 250 feet deep, passing through sand 10 feet, clay 30 feet, gravel 210 feet. Ice supply is cut from Sand Hill River. No sewerage. Garbage is hauled to the village dumping ground and buried.

Fosston, Polk County.—On Sand Hill River, 30 miles above Fertile. Water supply is obtained from a dug well, 40 feet deep by 20 feet in diameter. Ice supply is taken from lakes near the village. No sewerage. No regular garbage disposal.

Frazee, Becker County.—On Ottertail River, 60 miles above Fergus Falls. No waterworks. Ice supply is cut from Carow Lake, 1 mile east of the village. Garbage is commonly removed to the village dumping ground.

Graceville, Bigstone County.—Water supply is obtained from a deep well. No report on sewerage. Ice supply is cut from Bigstone Lake. Garbage is burned or hauled outside the village limits.

Grand Forks, Grand Forks County, North Dakota.—On Red River, at its confluence with Red Lake River. Water supply is taken from Red Lake River at its entrance into Red River. The water is purified by a slow sand-filtration plant having a capacity of 1,000,000 gallons a day. Ice supply is cut from Maple Lake and Red River. A combined sewerage system empties into Red River. The University of North Dakota and Wesleyan University are located near the city.

Hallock, Kittson County.—On Two Rivers about 10 miles in a direct line above its entrance into Red River. Water supply is taken from the river unfiltered. Ice supply is cut from Two Rivers. No sewerage. Garbage is hauled to the village dumping grounds.

Herman, Grant County.—A short distance north of the South Fork of Mustinka River. Water supply is obtained from a 6-inch tubular well, 122 feet deep, penetrating the following strata:

Log of well at Herman, Grant County.

	Feet.
Black loam	2
Yellow clay	17
Blue clay containing small bowlders	40
Hardpan	1
Blue clay and quicksand	60
Water-bearing gravel	2

The village has no public sewerage.

Lake Park, Becker County.—On Lake Flora, which is connected with Buffalo River. Water supply is obtained from an 8-inch well, 350 feet deep, which passes through the following strata:

Log of well at Lake Park, Becker County.

	Feet.
Loam	3
Yellow clay	130
Blue clay	60
Hardpan	10
Gravel	20
Hardpan	118
Quicksand	6
Gravel	3

Ice supply is cut from Lakes Labella and Boyer, near the village. No sewerage.

Moorhead, Clay County.—On Red River 97 miles below its head. Water supply is taken from Red River unfiltered; ice supply from Red River and Detroit Lake. A combined sewerage system discharges into Red River. Garbage is commonly hauled to the city dumping grounds. A State normal school, 500 pupils, and Concordia College, 400 pupils, are situated in Moorhead.

Pelican Rapids, Ottertail County.—On Pelican River. No waterworks; storm sewerage; ice supply from Pelican River.

Perham, Ottertail County.—Near Ottertail River. Ice supply is cut from Little Pine Lake and Ottertail River. Water supply for fire protection is taken from one large well. No sewerage.

Red Lake Falls, Red Lake County.—On Red Lake River at its confluence with Clearwater River. No waterworks or sewerage. Ice supply is cut from Red Lake River. Garbage is hauled to the public dumping ground and buried.

St. Hilaire, Red Lake County.—On Red Lake River 50 miles above Red Lake Falls. No waterworks or sewerage. Ice supply is cut from Red Lake River. Garbage is hauled to the village dumping ground.

Thief River Falls, Red Lake County.—On Red Lake River about 50 miles below Red Lake. No waterworks or sewerage. Ice supply is taken from Red Lake River below the entrance of Thief River. Garbage is regularly removed during the summer.

Wahpeton, Richland County, North Dakota.—Opposite Breckenridge at confluence of Ottertail and Bois de Sioux rivers. Water and ice supply from Ottertail River. No report on sewerage. Garbage hauled outside the city limits.

Warren, Marshall County.—On Snake River. Water supply is taken from an 8-inch artesian well, 200 feet deep, sunk through clay, hardpan, and sand. Ice supply is cut from Snake River above the dam. No sewerage. Garbage is regularly removed to the village dumping ground and buried during the summer months.

Wheaton, Traverse County.—On Mustinka River. Water supply is obtained from two wells, one 8 feet square by 150 feet deep, curbed with plank, the other 4 inches in diameter by 180 feet deep, with an iron casing. Ice supply is taken from a small creek entering Mustinka River. Garbage is burned at the village dumping ground. A combined sewerage system discharges into Mustinka River.

RAINY RIVER BASIN.

GENERAL DESCRIPTION.

The Rainy River basin, lying along the northern boundary, is more thinly settled and less fully explored than any other part of the State. A chain of lakes forms the international boundary from North Lake, in the northeastern part of Cook County, to Rainy Lake. Rainy River runs westward along the border to Lake of the Woods, which is connected with Hudson Bay by Nelson River. The area is bounded on the north by the Dominion of Canada, on the east by the Laurentian basin, on the south by Mississippi Valley, and on the west by Red River drainage area. It includes the northern parts of Cook, Lake, St. Louis, Itasca, and Beltrami counties, comprising an area of 9,675 square miles.[a] It is in large part covered with pine forests, but contains many large swamps, which by artificial drainage will become productive lands. The principal tributary of the Rainy River system is Vermilion River, which rises in Vermilion Lake, a large body of water of very irregular form, not very deep, situated in the north-central part of St. Louis County, on the western edge of the Vermilion iron-bearing district, at an elevation of about 1,330 feet above sea level. From a northern arm of this lake Vermilion River runs northward, with numerous falls and rapids, to Crane Lake, and empties into one of the chain of lakes forming the northern boundary. Other important tributaries are Bowstring River, which enters Rainy River about 15 miles below Rainy Lake and drains much of Itasca County, and Little Fork River, which enters Rainy River a short distance above Bowstring River.

[a] Hall, C. W., Geography and geology of Minnesota, vol. 1, p. 151, Minneapolis, Minn., 1903.

INDUSTRIAL POLLUTION.

At present there is in this area practically no pollution of rivers from industries. One brewery and two sawmills are located at Tower, on the shore of Tower Bay, an arm of Vermilion Lake. Koochiching, now a frontier village at International Falls, near the outlet of Rainy Lake, is likely to become a manufacturing center and may sometime be the site of important industries. Near Tower and at Ely there are large shaft mines from which considerable water is pumped. This drainage is unimportant and will probably never cause any trouble.

MUNICIPAL POLLUTION.

As previously stated, Rainy River basin is the most thinly settled area in the State. The following table shows the distribution of population:

TABLE 74.—*Population of Rainy River basin in Minnesota.*

County.	Population.		
	U. S. census, 1890.	U. S. census, 1900.	State census, 1905.
Beltrami		2,949	3,504
Itasca	100	886	1,985
St. Louis	4,879	11,251	13,593
Roseau		1,398	238
Bois Fort Indian Reservation	(a)	(a)	762
	4,979	16,484	22,082

a Given in county population.

TABLE 75.—*Density of population in Rainy River basin in Minnesota.*

[Drainage area, 9,675 square miles.]

Area considered.	Inhabitants per square mile.		
	1890.	1900.	1905.
Entire basin in Minnesota	0.5	1.7	2.3
Excluding chief settlements	.3	1.2	1.7

More than half the inhabitants of this basin live in the Vermilion district of St. Louis County, and most of them are concentrated at Ely and Tower. The pollution from population is therefore inappreciable, except, possibly, in the vicinity of these two places. Ely, a city of 4,045 inhabitants, is on Long Lake, to which its sewage goes. Tower, with 1,340 inhabitants, is on a bay connected with Vermilion Lake. The rapid growth of population in this section and the advantages it presents to settlers indicate that it will soon be as thickly inhabited as any farming section of the State.

QUALITY OF WATER.

Very few chemical or bacteriological examinations of the water in this basin have been made, and not much is known regarding its quality. Since the rocks of this region are hard and insoluble, and the drift is largely derived from granite, schists, and slates, it is fair to presume that the waters will not be extremely hard. Samples were collected from Tower Bay and Vermilion Lake, outside Tower Bay near Tower, as well as from the head and the foot of Long Lake and from over the waterworks intake at Ely. Analyses of these are given in Table 76.

The water of Tower Bay shows a higher color than that of the main lake, but in other respects it is much the same. *B. coli communis* was isolated once from the water of Tower Bay. This was in the spring when flood conditions prevailed, after the ice had gone out. The bacterial count was generally low. The water of Long Lake at Ely is soft. It contains little matter that could be called incrusting, but its color makes the use of a coagulant desirable in its purification.

NOTES ON MUNICIPALITIES.

Ely, St. Louis County.—On south shore of Long Lake. Water supply is taken from Long Lake and purified by a Continental Jewell filter, with alum coagulant supplemented by a large sedimentation tank. Ice supply is cut from Long Lake. Sewerage discharges into Long Lake. Garbage is regularly removed to the village dumping ground and burned.

Soudan, St. Louis County.—Near Tower. No waterworks or sewerage. Ice supply is cut from a small pond. Garbage is hauled outside the village limits.

Tower, St. Louis County.—On shore of Tower Bay, an arm of Vermilion Lake. Water supply for fire protection is taken from a small creek running through town. Ice supply is cut from East Two Rivers. No sewerage. Garbage is hauled to the village dumping ground.

MISSOURI RIVER BASIN.

GENERAL DESCRIPTION.

In the southwest corner of the State, parts of Pipestone, Rock, Murray, Jackson, Lincoln, and Nobles counties are drained by streams tributary to Missouri River, principally by Rock River. This stream has its source in Etna Township, Pipestone County, flows southward, and enters Big Sioux River near Calliope, Iowa. Little Sioux River has its source near Lakefield, Jackson County, flows southwestward across Iowa, and discharges into Missouri River near River, Iowa.

Locality and source.	Date.	Color.	Odor.	Turbidity.	Chlorine.	Sulphate radicle.	Total alkalinity.	Total hardness.	Iron.	Total residue.	Soluble residue.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Bacteria per c.c.[a]	B. coli communis.[a]
Tower Bay:																	
At Tower[b]	Nov. 30, 1903	324	3v	13	1.3	0	16	34	.....	.....	.....	0.25	0.13	0.000	0.00	200	−
Do.[b]	Feb. 5, 1904	.....	.....	<7	.3	0	24	51	.....	.....	.....	.32	.42	Trace.	.00	.....	−
Do.[b]	May 10, 1904	148	2v	12	.3	0	18	36	0	.....	.....	.52	.19	.000	Trace.	104	+
Vermilion Lake:																	
At Tower[b]	Feb. 5, 1904	60	.....	<7	.2	0	23	41	.....	.....	.....	.28	.07	.000	Trace.	18	.....
Do.[b]	May 10, 1904	74	2v	<7	.3	0	22	36	0.5	.....	.....	.26	.09	.000	Trace.	10	−
Do.[c]	Sept. 17, 1904	56	0	11	.7	0	26	35	0	70	23	.470	.056	.000	Trace.	70	−
Long Lake at Ely:																	
Upper end[b]	Feb. 6, 1904	40	0	<7	.2	Trace.	29	44	.....	.....	.....	.37	.21	Trace.	Trace.	.....	−
Do.[b]	May 9, 1904	50	2v	<7	.3	0	15	36	Trace.	.....	.....	.28	.08	.000	Trace.	250	+
Do.[c]	Sept. 18, 1904	40	2v	11	.4	0	26	26	0	43	11	.202	.022	.000	.00	250	−
At intake[b]	Feb. 6, 1904	44	0	<7	.2	Trace.	26	37	.....	.....	.....	.225	.085	Trace.	Trace.	.....	−
Do.[b]	May 9, 1904	56	0	<7	.3	.....	.....	29	.....	.....	.....	.30	.04	.00	Trace.	110	−
Do.[b]	June 5, 1904	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.18	.10	.00	.00	50	−
Do.[c]	Aug. 15, 1904	44	1v	<7	.9	.....	25	28	.....	83	.....	.262	.070	.00	.00	75	+
Lower end[b]	Dec. 1, 1903	15	.....	<7	.....	0	27	34	.....	.....	.....	.....	.....	.....	.....	33	−
Do.[b]	Feb. 6, 1904	40	0	<7	.2	Trace.	25	34	.....	.....	.....	.22	.09	.00	Trace.	20	−
Do.[b]	May 9, 1904	44	0	<7	.3	0	26	42	Trace.	.....	.....	.26	.07	.00	Trace.	.....	.....
Do.[c]	Sept. 18, 1904	40	2M	11	1.2	0	27	28	0	65	8	.380	.032	.000	.00	100	+

[a] Bacteriological examinations by Dr. E. H. Beckman.
[b] Nitrogen and chlorine determinations by H. C. Carel; other determinations by R. B. Dole.
[c] Analyses by R. B. Dole.

MUNICIPAL POLLUTION.

This is in general a farming area, with only small trading centers. The population is shown in Table 77.

TABLE 77.—*Population in Missouri River basin in Minnesota.*

County.	Population.		
	1890.	1900.	1905.
Pipestone	5,132	8,941	9,339
Lincoln	1,139	1,793	1,998
Rock	6,817	9,668	9,729
Murray	631	1,103	1,648
Nobles	3,979	7,466	7,528
Jackson	820	1,304	1,306
	24,518	30,195	31,348

TABLE 78.—*Density of population in Missouri River basin in Minnesota.*

[Drainage area, 1,550 square miles.[a]]

	Population per square mile.		
	1890.	1900.	1905.
Entire basin	15.8	19.5	20.2
Excluding chief settlements	13.6	15.6	16.1

[a] Hall, C. W., op. cit., p. 151.

NOTES ON MUNICIPALITIES.

Adrian, Nobles County.—On Kanaranzi Creek, 15 miles above its entrance into Rock River. Water supply is obtained from a large well, ice supply from Kanaranzi Creek. No sewerage. Manure is hauled to adjacent farms; other combustible rubbish is usually burned.

Lakefield, Jackson County.—On Little Sioux River [a] near its head. Water supply is derived from an 8-inch tubular well, 185 feet deep, passing through black loam 2 feet, yellow clay 42 feet, sand 2 feet, blue clay hardpan 130 feet, sand 9 feet. Ice supply is cut from Heron Lake. No sewerage. Manure is regularly hauled to the village dumping ground. House garbage is privately collected and fed to hogs.

Luverne, Rock County.—On Rock River. Water supply is taken from a well in the river bottom, 22 feet deep by 20 feet in diameter, stoned and cemented and covered by a wooden roof. It passes through top soil 2 feet, clay 5 feet, gravel 6 feet, quicksand 7 feet. Ice supply is cut from Rock River above the city. Sanitary sewerage discharges into Rock River. Garbage is hauled to the village dumping ground below the city.

Pipestone, Pipestone County.—Near Pipestone Creek, which flows southward into Sioux River. Water supply is obtained from two

[a] Geol. Nat. Hist. Survey Minnesota, Final Rept., vol. 6, Pl. XIX.

wells in the city; one 6 inches in diameter by 200 feet deep, entering rock at 30 feet; the other 8 inches in diameter by 365 feet deep, entering rock at about the same depth. Ice supply is cut from a small lake on the neighboring Indian reservation and from Pipestone Creek. Garbage is hauled to the village dumping ground.

DES MOINES RIVER BASIN.

GENERAL DESCRIPTION.

Des Moines River basin in Minnesota is situated near the southern border of the State. The river has its source in two branches, which flow southward, uniting near Humboldt, Iowa; thence it flows southeastward across Iowa to Mississippi River near Keokuk. The east fork rises in Jay Township, Martin County, and flows through Tuttle Lake into Iowa. The west fork, which is much larger and longer, has its source in Rainy Township, Pipestone County, on the east slope of the Dakota foothills, and flows thence generally southeastward into Iowa, draining parts of Murray, Nobles, Cottonwood, and Jackson counties. It is a fairly swift stream about 100 feet wide and 5 to 6 feet deep.

MUNICIPAL POLLUTION.

Des Moines River basin in Minnesota is a well-settled portion of the State, comprising general farming districts and a few manufacturing and trading centers.

TABLE 79.—*Population of Des Moines River basin in Minnesota.*

County.	U. S. Census, 1890.	U. S. Census, 1900.	State census, 1905.
Cottonwood	2,400	4,234	4,290
Jackson	8,104	13,489	13,572
Martin	1,642	2,779	2,926
Murray	6,061	10,808	10,069
Nobles	3,979	7,466	7,528
Total	22,186	38,776	38,383

TABLE 80.—*Density of population in Des Moines River basin in Minnesota.*

[Drainage area, 1,847 square miles.[a]]

	Population per square mile.		
	1890.	1900.	1905.
Entire basin in Minnesota	12.0	21.0	20.8
Excluding chief settlements	10.5	17.7	17.5

[a] Hall, C. W., op. cit., p. 151.

TABLE 81.—*Chief settlements in Des Moines River basin in Minnesota.*

Locality.	Population.		
	1890.	1900.	[illegible]
Jackson	720	1,788	[illegible]
Windom	835	944	[illegible]
Worthington	1,164	2,386	[illegible]
Total	2,719	6,068	[illegible]

NOTES ON MUNICIPALITIES.

Fulda, Murray County.—Near Sevenmile Lake, now usually call[illegible] Fulda Lake. Water supply is obtained from a well 230 feet de[illegible] entering rock. Ice supply is cut from Sevenmile Lake. No sewe[illegible] age. Garbage is irregularly hauled outside the village.

Heron Lake, Jackson County.—Near north end of Heron La[illegible] which is connected by a small lake with Des Moines River. [illegible] waterworks or sewerage. Ice supply is cut from Heron La[illegible] Garbage is dumped on the ground about 1 mile from the village.

Jackson, Jackson County.—On Des Moines River. Water supp[illegible] is obtained from a well dug in gravel, 20 feet square by 20 feet de[illegible] and walled with brick. There is also an emergency connection wi[illegible] Des Moines River. Garbage is removed to the village dumpi[illegible] ground. A combined sewerage system discharges into Des Moine[illegible] River.

Slayton, Murray County.—On Beaver Creek. Water supply is obtained from one 8-inch well, 205 feet deep, sunk through hardpan, clay, and gravel. Ice supply is cut from Badger Lake. The village is equipped with storm and sanitary sewerage. Garbage is removed to a dumping ground outside the village.

Windom, Cottonwood County.—On Des Moines River. Water supply is procured from wells. One is an 8-inch well, 280 feet deep. There is also a shallow dug well, 20 feet deep, in the bottom of which about thirteen 3-inch points have been driven to a depth of 60 feet in the gravel. Ice supply is cut from Des Moines River above the dam. No sewerage. Garbage is commonly hauled to adjacent farms.

Worthington, Nobles County.—On Lake Okabena. Water supply is obtained from four driven wells 60 feet deep, three of which are 10 inches and one 8 inches in diameter. At the time of an investigation of the city supply in 1905 a connection existed between the reservoir, into which the well water was discharged, and a cistern that held water coming from a trench or collecting gallery on the shore of Lake Okabena. Ice supply is cut from Lake Okabena. A combined sewerage system discharges into a small creek that runs northward from the city. No systematic garbage disposal.

CEDAR RIVER BASIN.

GENERAL DESCRIPTION.

Cedar River rises in Hayfield Township, Dodge County, and flows southward across Mower County into Iowa; then, turning slightly to the east, it flows across that State to Mississippi River. It drains parts of Dodge, Mower, and Freeborn counties.

MUNICIPAL POLLUTION.

TABLE 82.—*Population of Cedar River basin in Minnesota.*

County.	Population.		
	1890.	1900.	1905.
Dodge	1,974	2,444	2,342
Freeborn	13,077	16,059	16,843
Mower	13,313	16,715	21,385
Total	28,364	35,228	40,570

TABLE 83.—*Density of population in Cedar River basin in Minnesota.*

[Drainage area, 1,165 square miles.[a]]

	Inhabitants per square mile.		
	1890.	1900.	1905.
Entire basin	24.3	30.2	34.8
Excluding chief settlements	18.2	21.7	24.4

[a] Hall, C. W., op. cit., p. 151.

Austin, one of the important cities of the State, situated on Cedar River, about 20 miles above the Iowa boundary, discharges its sewage directly into the stream. Albert Lea, in Freeborn County, on Shell-rock River, a tributary of Cedar River, also discharges its sewage into the stream. No analyses of surface waters were made in Cedar River basin during the cooperative work.

NOTES ON MUNICIPALITIES.

Albert Lea, Freeborn County.—Near the upper end of Lake Albert Lea, which is drained by Shell Rock River. Water supply is procured from an artesian well 650 feet deep.[a] Ice supply from Fountain Lake above the city. No report on sewerage.

[a] Bien. Rept. Minnesota State Bd. Health, 1899-1900, p. 172.

Austin, Mower County.—On Cedar River. Water supply is obtained from five drilled wells—one 150 feet, one 400 feet, and three 600 feet deep—passing through the following strata:

Log of well at Austin, Mower County.

	Feet
Drift	[illegible]
Limestone	[illegible]
Shale	[illegible]
Limestone	[illegible]
Shale	[illegible]
Sandstone	[illegible]

The supply of the deeper wells is probably derived from the "St. Peter" sandstone. There is also an emergency connection with Cedar River. Ice supply is cut from Cedar River. Separate storm and sanitary sewerage discharge into Cedar River. Garbage is removed to the public dumping ground. The Southern Minnesota Normal College and School of Commerce, with 100 to 700 pupils, is situated at Austin.

Blooming Prairie, Steele County.—Near the west fork of Cedar River. Water supply is procured from a 10-inch tubular well, 244 feet deep, which is sunk about 100 feet in the rock. Ice supply is cut from Cedar River. Public sewerage. Part of the garbage is carted outside the village limits.

Glenville, Freeborn County.—On Shell Rock River. No waterworks or sewerage. Ice supply is taken from Shell Rock River.

MUNICIPAL WATER SUPPLIES.

EXTENT OF PUBLIC SUPPLIES.

In order to ascertain the extent to which surface waters are used for public supplies in Minnesota, inquiries were made in over 200 of the principal settlements of the State. Nearly 50 per cent of this information was obtained by visits to the municipalities. The remainder was derived from statements signed by the city or village clerk and by the superintendent of waterworks where there is one. It is believed that fairly accurate information has thus been gained concerning the condition of the water supplies before July, 1905. The results of the inquiry are summarized in the accompanying tables. Table 84 comprises towns supplied with ground water. In the last column it is noted whether there is an emergency connection with an adjacent surface supply. Table 85 gives the names of places having surface supplies, the source of the water, and, under "Remarks," pertinent observations regarding some supplies. Table 86 gives the names of settlements that were reported to be without public waterworks at the close of the inquiry (July, 1905). Hender

son, Jordan, and Olivia are the only important settlements that failed to report on waterworks. Table 87 comprises places that have public supplies whose source is not reported.

TABLE 84.—*Places having ground-water supplies.*

Locality.	Source of supply.	Depth.	Diameter of well.	Remarks.
Ada	2 tubular wells through clay to sand.	265 feet	2 inches	Auxiliary supply from State ditch.
Adrian	1 large well	47 feet [a]	12 feet [a]	
Albert Lea	Artesian wells in rock			
Alden	1 deep well	100 feet [a]		
Alexandria	Dug well	30 feet	20 feet	
Appleton	1 well			Connection with Pomme de Terre River.
Austin	5 wells drilled in sandstone	One 150 feet One 400 feet Three 600 feet	One 7½ inches Four 11¾ inches	
Belle Plaine	1 well			
Bemidji	5 driven wells in swamp	106 feet	3½ inches	
Benson	2 wells			
Bird Island	1 tubular well	285 feet	8 inches	
Biwabik	Dug well through clay into gravel.	175 feet	9 feet square	
Black Duck	2 driven wells	90 feet	4 inches	
Blooming Prairie	1 tubular well in the rock	244 feet	10 inches	
Blue Earth	2 drilled wells; supply from sandstone.	375 feet 672 feet	6 inches 8 inches	
Browns Valley	Springs in side of bluff			
Caledonia	1 drilled well; supply from sandstone.	318 feet	8 inches	
Cambridge	1 drilled well in sandstone	140 feet	do	
Cannon Falls	1 drilled well	400 feet	do	
Cass Lake	4 driven wells in sand	28 feet		
Chaska	1 drilled well	640 feet	8 inches	Chiefly used for fire protection.
Chatfield	1 drilled well; supply from rock.	200 feet	6 inches	
Deer River	1 flowing well through clay into gravel.	96 feet	3 inches	
Detroit	Shallow dug well			
Elmore	1 well	300 feet	6 inches	
Faribault	2 artesian wells 2 surface wells	800 feet 700 feet 20 feet		
Fertile	1 well through clay into gravel.	250 feet	6 inches	
Fort Snelling	Artesian well; supply from sandstone.	636 feet	10 inches	
Fosston	1 dug well through clay into sand.	40 feet	20 feet	
Fulda	1 well entering rock	230 feet		
Glencoe	1 drilled well; supply from sandstone.	1,728 feet	8 inches	
Glenwood	Springs			
Graceville	Deep well			
Grove City	1 deep well	740 feet	8 inches	
Hector	do	420 feet	do	
Herman	1 tubular well through clay into gravel.	122 feet	6 inches	
Hibbing	Dug well; old prospecting shaft.	215 feet		
Hutchinson	1 drilled well	160 feet	10 inches	
Jackson	1 dug well in alluvial gravel	20 feet	20 feet square.	Connection with Des Moines River.
Janesville	1 well; supply from gravel	75 feet	3 inches	
Kasson	1 well drilled in rock	200 feet	8 inches	
Kenyon	1 shallow well	25 feet		
Lake Benton	1 well			
Lake City	1 dug well in sand			Emergency connection with Lake Pepin.
Lake Crystal	1 well drilled in rock	775 feet	8 inches	For fire purposes only.
Lakefield	1 tubular well	185 feet	8 inches	Supply from sand.
Lake Park	1 well; supply from gravel	350 feet	8 inches	
Lanesboro	A spring in side of bluff	3 feet	30 feet square.	

[a] Bien. Rept. Minnesota State Bd. Health, 1899-1900, pp. 168-204.

TABLE 84.—*Places having ground-water supplies*—Continued.

Locality.	Source of supply.	Depth	Diameter of well.	Remarks.
Le Sueur	1 drilled well	668 feet	8 inches	
Litchfield	Driven wells in gravel	42 feet	2 inches	
Long Prairie	2 dug wells; masonry lining	20 feet 40 feet	12 feet 30 feet	
Luverne	1 well dug in quicksand	22 feet	20 feet	
McKinley	Driven points in gravel on shore of lake.	45 feet	5 inches	See p. 122.
Madelia	2 wells	206 feet	6 inches	
Madison	Dug wells			For fire protection only.
Mankato	2 artesian wells in rock	650 feet		
Mapleton	1 deep well	265 feet [a]		
Marshall	1 artesian well in rock, 1 deep well, 1 dug well 40 feet deep by 12 feet in diameter with 2 driven points in it.	410 feet 250 feet 70 feet 90 feet	 8 inches 4 inches 9 inches	
Minneota	1 tubular well; supply from sandstone.	105 feet	6 inches	
Montevideo	Collecting galleries in a gully north of town.			Emergency connection to Chippewa River.
Montgomery	1 well through blue clay	238 feet	10 inches	
Monticello	1 drilled well	237 feet	8 inches	
Mora	1 driven well	210 feet	10 inches	
Morris	5 driven wells in sand and gravel.	78 feet	8 inches	
Morton	Springs in gravel bluff			
Mountain Lake	1 dug well; stone curbing	10 feet		
New Prague	1 well	300 feet	8 inches	
New Ulm	6 drilled wells; supply from sandstone.	200 feet	Three 8 inches, two 6 inches, one 10 inches.	
Northfield	1 drilled well; supply from sandstone.	640 feet	8 inches	Iron collects in mains.
North St. Paul	1 well	300 feet	8 inches	Emergency connection with a lake.
Ortonville	1 dug well	45 feet	26 feet	
Owatonna	5 drilled wells in rock; 1 dug well 20 feet by 27 feet.	One 650 feet, one 90 feet, three 120 feet.	8 inches 5 inches 8 inches	120-foot wells in bottom of dug well.
Paynesville	4 tubular wells	80 feet	3 inches	
Perham	1 large well			For fire protection only.
Pipestone	2 wells entering rock at 30 feet.	200 feet 365 feet	6 inches 8 inches	
Plainview	2 drilled wells; supply from sandstone.	335 feet 700 feet	4¾ inches 5¾ inches	
Preston	1 spring			Inclosed with rock and covered.
Princeton	1 tubular well in gravel	187 feet	8 inches	
Redwood Falls	1 dug well	20 feet	12 feet	Connection with Redwood River.
Renville	1 well through clay into sand.	230 feet	8 inches	
Rochester	Bricked well in gravel and driven points (large well).	30 feet	30 feet	Emergency connection with Bear Creek.
Rush City	Shallow wells			Fire protection only.
Rushford	1 drilled well; supply from sandstone.	565 feet	6 inches	Objectionable odor.
St. Charles	1 well; supply from sandstone.	942 feet	10 inches	
St. James	2 drilled wells	185 feet 385 feet	8 inches 10 inches	Dug well for boiler use only.
St. Peter	1 dug well 1 drilled well in the rock	40 feet 350 feet	 8 inches	
Sandstone	2 wells drilled in sandstone	150 feet 750 feet	10 inches 12 inches	
Sherburne	1 artesian well	200 feet [a]		
Slayton	1 tubular well	205 feet	8 inches	Supply from sand and gravel.
Sleepy Eye	Dug well with casing in bottom driven to rock.	20 feet	20 feet	
South St. Paul	Artesian wells			
South Stillwater	Dug and stoned well connected with a brook.	25 feet	20 feet	For fire protection only.

[a] Bien. Rept. Minnesota State Bd. Health, 1899-1900, pp. 168-204.

TABLE 84.—*Places having ground-water supplies*—Continued.

Locality.	Source of supply.	Depth.	Diameter of well.	Remarks.
Springfield	1 well	28 feet	6 inches	
Spring Valley	1 spring			
Stewartville	1 well drilled in rock	62 feet	8 inches	
Stillwater	Spring and a deep well	750 feet	8 inches	Auxiliary supply from Lake McKusick. See p. 95.
Tracy	1 drilled well	500 feet	10 inches	
Virginia	Driven well			Emergency connection with Silver Lake.
Wadena	1 dug well in gravel	22 feet	20 feet	
Warren	1 well through hardpan to sand.	200 feet	8 inches	
Waseca	2 drilled wells	400 feet 1,000 feet	10 inches	
Waterville	1 drilled well	185 feet	8 inches	
Wells	2 wells	200 feet	8 inches 12 inches	
West Minneapolis	1 drilled well	600 feet	8 inches	For fire protection only.
Wheaton	2 wells	150 feet 180 feet	8 feet by 8 feet 4 inches	
White Bear Lake	1 deep well		10 inches	
Willmar	Wells	240 feet		
Windom	1 dug, 1 drilled, and 13 driven wells.	One 20 feet One 280 feet Thirteen 60 feet	14 feet 8 inches 3 inches	Points driven in bottom of shallow well.
Winnebago City	1 well	283 feet	8 inches	
Winona	2 wells in alluvium	35 feet	50 feet	Connection with Mississippi River.
Winthrop	1 tubular well; supply from gravel and sand.	239 feet	10 inches	
Worthington	4 driven wells	60 feet	Three 10 inches, one 8 inches.	
Zumbrota[a]	1 well drilled into limestone	210 feet		

[a] Bien. Rept. Minnesota State Bd. Health, 1901-2, p. 327.

TABLE 85.—*Places having surface water supplies.*

Locality.	Source of supply.	Filtered.	Remarks.
Aitkin	Mud River	No	
Anoka	Rum River	No	
Brainerd	Mississippi River		Filtering capacity inadequate.
Breckenridge	Ottertail River	No	
Crookston	Red Lake River	No	
Delano	Crow River	No	For fire protection only.
Duluth	Lake Superior	No	
Ely	Long Lake	Yes	
Eveleth	St. Marys Lake	No	
Fairmont	Lake Budd	No	
Fergus Falls	Ottertail River	No	
Grand Rapids	Hale Lake	No	
Granite Falls	Minnesota River	No	So-called filter of no practical value.
Hallock	Two Rivers	No	
Little Falls	Mississippi River	No	
Melrose	Sauk River	No	For fire protection only.
Milaca	Rum River	No	Do.
Minneapolis	Mississippi River	No	
Moorhead	Red River	No	
Osakis	Osakis Lake	No	Do.
Park Rapids	Fishhook River	No	Little used for domestic purposes.
Red Wing	Mississippi River	No	For fire protection only.
St. Cloud	do	No	
St. Paul	Small lakes	No	Auxiliary supply from artesian wells. See p. 110.
Sauk Center	Sauk River	No	Little used for domestic purposes.
Sparta	Ely Lake	No	
Tower	Creek	No	For fire protection only.
Two Harbors	Lake Superior	No	
Walker	Leech Lake	No	

TABLE 86.—*Settlements having no public water supply.*

Argyle.	Farmington.	Sauk Rapids.
Audubon.	Frazee.	Scanlon.
Buffalo.	Glenville.	Shakopee.
Carlton.	Hastings.	Soudan.
Claremont.	Heron Lake.	St. Hilaire.
Cloquet.	North Branch.	St. Louis Park.
Cokato.	Ottawa.	Staples.
Dakota City.	Pelican Rapids.	Taylors Falls.
Dodge Center.	Pine City.	Thief River Falls.
East Grand Forks.	Proctorknott.	Waconia.
Elk River.	Red Lake Falls.	Wabasha.
Excelsior.	Royalton.	West St. Paul.

TABLE 87.—*Places whose source of supply is not reported.*

Akely.	Chisholm.	Westbrook.
Canby.	New London.	West Concord.

Several interesting facts are revealed by these tables. Possibly the most striking one is that only 15 settlements, with a population exceeding 1,000, according to the census of 1900, are without public water supplies. The next is that less than 25 per cent of the supplies are surface waters; while correlative with this seeming preponderance of ground supplies is the fact that St. Paul, Minneapolis, and Duluth, the three largest cities in the State, use surface water, except that the St. Paul system is provided with auxiliary wells. Among cities of moderate size those in the southern or older part of the State are generally supplied from wells, and those in the northern, or more recently settled part, are generally supplied from lakes or streams.

DEVELOPMENT OF WATERWORKS.

In the natural development of communities water supply is now one of the first public utilities to be considered. Many things which were once looked upon as luxuries are to-day necessities, and water available for use in the house and in the streets ranks high in this list. When, therefore, a newly established village is obliged to install waterworks in order to obtain reasonable insurance rates, an adjacent river or lake is seized upon as the most convenient source of supply for fire protection. When, subsequently, the householder desires to have running water in his dwelling, he discovers that the water of the river or lake is colored, turbid, or so polluted that it is undesirable. Since color and turbidity are the most obvious troubles they are avoided by the use of shallow wells in the line of seepage to the lake or stream. The householder then finds that the water from these shallow wells is invariably harder than the surface water; that it takes an enormous amount of soap to wash with it; that steam boilers are corroded or

scaled by it; and that frequently it contains so much iron that clothing washed in it is rusted and stained. The next move is to explore the deeper aquifers for more suitable water, and in regions where it is possible to obtain supplies in this manner deep wells are generally used as a source of public water. The wells, however, fail to meet the increasing demand and connection with the river is made for use in emergencies. The supply is then worse than ever from a hygienic point of view, for it is never known when the polluted surface water is in use or when after its use the pollution introduced into the system of pipes has disappeared. By increased consumption of the surface water, due to continued growth of urban population, the deep wells in turn become the auxiliary supply and are frequently abandoned altogether. Finally, the ultimate step of filtering the surface water is taken and the city has an abundance of safe, soft water. All settlements do not pass consecutively through every one of these stages. Some places, profiting by the experience of their neighbors, jump at once to the final solution of the problem, and some never progress beyond the first condition. Cities affording examples of all the different stages of development in water supply are found in Minnesota.

COMPARATIVE VALUE OF SURFACE AND GROUND WATERS.

Many factors other than the age of the settlement have, however, influenced a choice between surface and ground supplies. The quantity of water always has been, and doubtless always will be, the chief controlling condition. The supply and the demand, present and prospective, can be accurately estimated by mechanical contrivances, and the results of these measurements, reduced to gallons per day, can be comprehended by a majority of the consumers. There must be at all times sufficient amount of water and sufficient pressure to afford adequate protection in case of fire; sanitary appliances require fixed supplies for their proper performance of duty; sprinklers, hydraulic elevators, and steam boilers also demand a never-failing quantity; therefore the quality of the water is regularly subordinated to the quantity. In recent years, however, the quality has been receiving more and more attention. It has been demonstrated that certain diseases are transmissible by water. It has been shown by experience that water acceptable from a hygienic point of view will not be drunk if it is muddy, highly colored, or odoriferous. With increased scrutiny of the cost of production in industries, the removal of the hardening constituents of water is receiving more careful attention.

As has been noted in previous pages, very few surface water supplies in Minnesota are well protected against pollution, and many of them are therefore likely to become the vehicles for the transportation of pathogenic bacteria. Without engaging in a lengthy discussion of the problem it may be said that many of the shallow wells

used for public service are also exposed to danger of infection and that the users of them depend too much on the overtaxed filtration power of the surrounding soil or gravel. On the other hand, the deep wells, especially those in southern Minnesota, can probably be considered safe from a hygienic standpoint if they are carefully cased. Nearly all of the deep driven or drilled wells go through impervious strata, which effectually cut off surface drainage and protect the underlying water-bearing beds. Deep-well water is usually more satisfactory in "esthetic" qualities than raw surface water. In the northern or forested portion of the State many of the streams are frequently so highly colored that their water is undesirable for domestic use in its raw condition, and requires careful filtration before it can be made suitable for many industries. In the southern or prairie section of Minnesota floods scour the easily disintegrated banks of the streams and the resultant muddy water is objectionable. Some of the deep-well waters develop growths of micro-organisms that impart to them disagreeable odors or tastes and cause troublesome flocculent deposits in pipes. The surface waters are much softer than the ground waters. The deep-well waters carry more mineral matter than those of the lakes and streams in the same region for many reasons. They remain longer and more intimately in contact with the limestones and other rocks containing soluble minerals in the strata through which they pass. Their solvent action on the minerals with which they come in contact is greater than that of surface waters, because of their greater content of carbon dioxide, greater pressure, and other differences in physical conditions. In addition they are not so immediately subject to dilution by soft running water or by rains. Since the underground waters carry a large amount of scale-forming and corrosive ingredients, the task of procuring good water for use in locomotives and for other steaming purposes is difficult in some parts of southern Minnesota. The general employment of deep-well waters in laundries and for domestic purposes is not economical, for they must be artificially softened before they can be used. The reports of waterworks superintendents throughout the State show that in the majority of towns supplied with well waters it is necessary to use preheaters and boiler compounds to make the water suitable for steaming purposes. Soda ash, trisodium phosphate, oils, vegetable mixtures, and all kinds of proprietary boiler compounds are commonly employed. In the smaller cities such trouble as this is not so serious as absolutely to prohibit the use of hard well water, but in the large cities it has been found necessary to provide a soft surface water for steaming purposes, because the cost of softening the well water would economically prohibit its use. At present the solutions of the problem seem to be, on one hand, the filtration of the unpro-

tected surface supplies, or, on the other, the adoption of two separate systems, with deep-well water for general domestic use and with raw lake or stream water for fire protection and industrial use. The latter is costly to install and affords a menace to health, since, if available, it might lead to the use of an unsafe supply for drinking and other domestic purposes.

METHODS OF ANALYSIS.

CHEMICAL EXAMINATIONS.

Field assays.—Color, turbidity, iron, chlorine, sulphates, alkalinity, and total hardness were determined according to the methods outlined in Water-Supply Paper 151, entitled "Field Assay of Water." Odor was determined cold and expressed as outlined in Tables 92 and 93. The field analyses were all made under cover, either in a hotel room or in the office of the local health officer. The determinations of color, odor, iron, and turbidity are comparable in accuracy with laboratory results obtained by the same procedures. The determination of chlorine is probably least accurate on account of its relatively low percentage in the waters as compared with the strength of silver nitrate tablet used. The high color of some samples, error in measuring the amount of water used, and the variation in the strength of tablet may all be sources of error in the determination of alkalinity. These factors may cause a probable error of 5 to 10 parts per million. In case total sulphates were too low for determination by the turbidimeter, the amount was estimated by the cloudiness of the precipitated fluid when held up to the light. Total hardness was so low in nearly all cases that the results are comparable with laboratory figures obtained by using soap solution. When turbidity was less than 7 on the graduated turbidity rod the expression "<7" has been used.

Laboratory analyses before August, 1904.—Samples were collected in 2-quart cork-stoppered or 1-gallon glass-stoppered bottles and shipped in locked wooden boxes to the laboratory, where they were submitted to chemical examination. A few analyses were made by Prof. G. B. Frankforter, dean of the chemical department, University of Minnesota, or by Dr. E. H. Beckman, assistant bacteriologist, Minnesota State board of health. Standard methods were used in the work, and the results are comparable with any laboratory analyses. The greater part of the chemical laboratory work done during this period was performed by H. C. Carel, assistant professor of medical chemistry, University of Minnesota, who was employed by the State board of health to make chemical examinations of water. He determined quantitatively chlorine, ammonias, and total hardness according to current methods.

Laboratory examinations after August, 1904.—The chemical analy made between August 1, 1904, and July 1, 1905, were performed b R. B. Dole, assistant hydrographer, United States Geological Surve Color, turbidity, iron, and sulphates were determined according t the methods outlined in Water-Supply Paper 151 and circular 9 the hydrographic branch. Since it was believed that the importan of the determination of sulphates did not warrant the more laborio gravimetric method, the Jackson electric turbidimeter was used i nearly all cases. In the determination of iron the samples were boil vigorously with nitric acid in order to insure complete change of th iron to the ferric form.

Chlorine, free and albuminoid ammonia, and nitrates were deter mined according to the methods described by Mason[a] with som exceptions. If the chlorine content was less than 5 parts per million 250 cubic centimeters of the sample were concentrated on the wate bath with 1 drop of strong sodium carbonate solution before titra tion. Albuminoid ammonia was determined on the residue after the free ammonia estimate by distilling five 50 cubic centimeter tube after adding a freshly-boiled alkaline permanganate solution. Many of the samples were highly colored and were decomposed very slowly by the oxidizing agents employed.

Nitrites were determined by the Ilosvay modification of the Greiss method: 0.5 gram sulphanilic acid was dissolved in 150 cubic centimeters acetic acid (specific gravity 1.04); 0.1 gram naphthylamine hydrochloride was boiled in 20 cubic centimeters of water, filtered through a plug of absorbent cotton, diluted to 200 cubic centimeters with acetic acid (specific gravity 1.04), and mixed with the sulphanilic acid solution. Five cubic centimeters of this reagent was added to 100 cubic centimeter amounts of the waters under examination in beakers and coincidently to appropriate dilutions of a standard nitrite solution. By comparison of the colors at the end of twenty minutes the amount of nitrites was estimated. Both nitrites and nitrates are reported as nitrogen.

Alkalinity was estimated by titrating with N/50 sulphuric acid, using methyl orange indicator. Free carbon dioxide was found by titrating with N/10 sodium carbonate, using phenolphthalein indicator.

For total solids 100 cubic centimeters of the sample was evaporated to dryness on the water bath in a tared platinum dish, dried at 110° C. for two hours, cooled, and weighed. For "soluble solids" the total residue was extracted for ten-minute periods with three successive portions of 20 cubic centimeters each, of 65 per cent alcohol; after each digestion the alcohol was carefully decanted; finally, the residue

[a] Mason, W. P., Chemical examination of water, 1902.

°° C. for one-half hour, cooled, and weighed. This d approximately to separate the incrustants from the for silica, ferric oxide, calcium carbonate, calcium nagnesium carbonate are practically insoluble in 65 l. Therefore the difference between the total solids solids represents approximately the incrustants in the

ess was determined by titrating 50 cubic centimeters of iluted sample with standard soap solution as described The mineral content of most of the waters tested is he figure representing the so-called "total hardness" is alueless and frequently does not bear proper relation to rganic estimates.

tical data are expressed in parts per million. Odor is outlined in circular 8 of the hydrographic branch of the ording to the following tables:

TABLE 88.—*Description of odor.*

s. sweetish.	f. fishy.
o. oily.	d. disagreeable.
a. aromatic.	p. peaty.
e. earthy.	H_2S. hydrogen sulphide.

TABLE 89.—*Intensity of odor.*

Term.	Approximate definition.
one.....	No odor perceptible.
ery faint....	An odor that would not be ordinarily detected by the average consumer, but that could be detected in the laboratory by an experienced observer.
aint.....	An odor that the consumer might detect if his attention were called to it, but that would not otherwise attract attention.
Distinct.....	An odor that would be readily detected and that might cause the water to be regarded with disfavor.
Decided.....	An odor that would force itself upon the attention and that might make the water unpalatable.
Very strong...	An odor of such intensity that the water would be absolutely unfit to drink; a term to be used only in extreme cases.

BACTERIOLOGICAL EXAMINATIONS.[c]

llection of samples.—All samples were collected in glass-stop- bottles having a capacity of 300 cubic centimeters. After the een thoroughly washed the stoppers were placed in f twine rted between the stopper and the neck to pre stopper from sticking, a clean cloth

igated and employed by the Kennicott Water Softener y, chief chemist, Pennsylvania Lines.

es: Proc. Am. Pub. Health Assoc., vol. 30,

reaching well down on the neck of the bottles was put over the stopper and firmly tied to the neck with twine. The bottles thus prepared were sterilized by dry heat at a temperature of 160° C. for at least an hour. After the samples were collected the stopper was replaced, the cloth tied in position, and the sample labeled and taken to a hotel or some suitable place for making the plates. All plates were made within two hours of the time of collection.

Method of pouring plates.—All Petri dishes were wrapped in filter paper and sterilized by the same method and for the same length of time as the bottles previously mentioned. With a sterile pipette the desired amount of water was taken from the above-mentioned bottle after thorough shaking and placed in a sterile Petri dish. Tubes of plain agar and litmus lactose agar containing about 10 cubic centimeters of the media were melted in a portable water bath and allowed to cool nearly to the point of solidification (about 45° C. to 50° C.). The cotton plugs of these tubes were burned off in the open flame, the plug was removed, the mouth of the tube placed in the flame for a few seconds, and the contents of the tubes poured into the Petri dish containing the measured quantity of water. The cover of the Petri dish was immediately replaced and the contents of the dish were thoroughly mixed and evenly distributed in the usual manner. After the media had solidified, the Petri dish was labeled, replaced in the sterile filter paper, and shipped to the laboratory.

Quantity of water used.—Usually plain agar plates were made with 0.5 cubic centimeter and 0.1 cubic centimeter of water and litmus lactose plates with 0.5 cubic centimeter of water. These amounts were varied as circumstances demanded.

Estimation of average number of colonies.—The plain agar plates were used as a basis for all colony counts. These plates were incubated at a temperature of 22° C. for forty-eight hours after reaching the laboratory. Whenever it was possible the total number of colonies on each plate was counted. Otherwise a definite fraction was counted and the total number estimated from this count. In computing the average number of colonies from two or more plates containing different amounts of water the following method was used: The total number of colonies per cubic centimeter for each plate was multiplied by the number of tenths of a cubic centimeter used in making that plate; these amounts were then added and the sum was divided by the number of tenths of a cubic centimeter contained in all the plates. For example, suppose there were two plates made using 0.5 cubic centimeter and 0.1 cubic centimeter of water. The total number of colonies per cubic centimeter on the plate containing 0.5 cubic centimeter of water was multiplied by 5. To this amount was added the total number of colonies per cubic centimeter on the plate

containing 0.1 cubic centimeter of water and this sum divided by 6—that is, the number of tenths of a cubic centimeter used in making both plates; the result was taken as the average total number of colonies per cubic centimeter for this sample of water. Insignificant figures were rejected, according to the recommendations of the committee of the American Public Health Association on standard methods of water analysis.[a]

Method of determining the presence of B. coli communis.—To tubes containing about 1 cubic centimeter of double-strength plain agar melted in the water bath and allowed to cool to about the point of solidification, there was added 1 cubic centimeter of the water by means of a sterile pipette. The tube was then shaken, the mass allowed to solidify, and the tube labeled and shipped with the plates to the laboratory. Immediately upon its receipt at the laboratory the solidified mass was broken up into fine particles with a heavy sterile platinum needle and a tube of plain broth added. The mixture was then placed in the incubator. The litmus lactose agar plates made from each sample were incubated at 37° C. for twenty-four hours after reaching the laboratory and the total number of colonies as well as the acid colonies counted. If there were colon-like colonies on this plate, they were picked and streaked upon litmus lactose agar. If at the end of twenty-four hours this growth taken from individual colonies appeared to be pure, resembled *B. coli communis* under the microscope, and acidified the litmus lactose agar, it was further tested. If there were no colonies on the litmus lactose agar plate which resembled colon, the tube of plain agar which had been incubated for twenty-four hours, was sown into fermentation tubes, to which 0.1 per cent phenol had been added, and incubated for twenty-four hours longer. If gas formed in this tube, sowings were made from it, so that the colon-like organisms could be obtained in purity and tested. If no gas formed in the fermentation tube and no colon-like colonies appeared on the litmus lactose plate, it was reported that *B. coli communis* was not found in 1 cubic centimeter samples. Suspected organisms obtained in pure culture were sown in plain broth, Dunham's peptone solution, litmus milk, fermentation tubes containing 1 per cent dextrose broth, Löffler's blood serum, plain agar, dextrose, maltose, saccharose, and lactose litmus agars and potato. Indol was tested at the end of forty-eight hours and the gas reaction after the same length of time. In all instances where colon was found present its morphological appearance under the microscope and its motility were also determined.

[a] Proc. Am. Pub. Health Assoc., vol. 30, pt. 2, 1905, p. 84.

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[Water-Supply Paper No. 193.]

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WS 151. Field assay of water, by M. O. Leighton. 1905. 77 pp., 4 pls. (Out of stock.)

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

LLUTION OF ILLINOIS AND MISSISSIPPI RIVERS BY CHICAGO SEWAGE

A DIGEST OF THE TESTIMONY TAKEN IN THE CASE OF THE STATE OF MISSOURI V. THE STATE OF ILLINOIS AND THE SANITARY DISTRICT OF CHICAGO

BY

MARSHALL O. LEIGHTON

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POLLUTION OF ILLINOIS AND MISSISSIPPI RIVERS BY CHICAGO SEWAGE.

By M. O. Leighton.

INTRODUCTION.

OBJECT OF THE PAPER.

The testimony taken in the suit of the State of Missouri against the State of Illinois and the sanitary district of Chicago comprises the best symposium on river pollution, its biological and chemical aspects, and its general and special sanitary significance that has ever been assembled. The contentions of both parties to the suit are supported by the most eminently qualified men in the United States. The evidence presented and the discussions recorded are therefore of unique importance. The final record of testimony occupies 8,000 printed pages, much of which is irrelevant. This digest of testimony is the result of an attempt to recover the valuable material and present it in concise form. A consistent endeavor has been made by the reviewer to eliminate all personal opinions with reference to the issue and to make an impartial presentation of so much of the testimony as in his opinion appears to be relevant and of scientific importance. It will be well to remember in this connection that any digest of so large a volume of testimony must be the result of a final exercise of personal opinion by the reviewer as to those parts which may best be excluded. Naturally opinions will differ on this point; therefore it will be strange if many of those familiar with the case do not find that certain portions of testimony which they consider most important are passed over in this digest without reference. Controversies between counsel, objections to the admission of testimony, legal technicalities and quibbles, badgering cross-examination, and in general all the testimony introduced for purposes of mere corroboration have been disregarded. The object has been to present a faithful statement of the scientific phases of the testimony to the exclusion, if need be, of the legal aspect of the case.

Many of the averages contained in the tables of the official record appear to be incorrect. It does not appear whether this is due to

typographical errors or to mistakes by the original computers. Such tables as are reproduced in this digest are copied from the record without correction.

STATEMENTS OF PARTIES TO THE SUIT.

This is a proceeding in equity instituted by the State of Missouri on January 17, 1900, against the State of Illinois and the sanitary district of Chicago, praying for an injunction against the defendants from draining into Mississippi River the sewage and drainage of said sanitary district by way of the Chicago drainage canal and the channels of Desplaines and Illinois rivers.

BILL OF COMPLAINT.

The bill of complaint alleges in substance as follows:

That the complainant is a State lying on the west bank of Mississippi River with a frontage thereon of over 400 miles;

That the States of Illinois and Missouri have concurrent jurisdiction over the waters of Mississippi River, each having exclusive territorial jurisdiction over that portion adjacent to its shores, the boundary having been declared at the middle of the main channel;

That Illinois River joins the Mississippi at a point above St. Louis;

That on the banks of the Mississippi below its confluence is a large population that uses the water of the Mississippi for domestic, agricultural, and manufacturing purposes;

That the said water is indispensable to the life, health, and happiness of many thousands of inhabitants in Missouri;

That the construction of the Chicago drainage canal is such that its contents finally empty into Mississippi River about 43 miles above the city of St. Louis;

That such construction was done under the sanction and authority of the State of Illinois;

That the channel of said canal is cut through the natural watershed dividing the drainage area of Lake Michigan from that of Illinois River;

That the defendants propose to drain through said channel the sewage matter from nearly the whole of the city of Chicago and a portion of Cook County;

That for many years the city of Chicago had discharged into Lake Michigan large quantities of sewage which has accumulated upon the beds of Chicago River and of Lake Michigan;

That if such plan is carried out it will cause such sewage matter to flow into Mississippi River past the homes and waterworks systems of the inhabitants of the complainant;

That the amount of such undefecated sewage matter would be about 1,500 tons daily, and that it will poison the waters of the Mississippi and render them unfit for domestic use, amounting to a direct and continuing nuisance that will endanger the health and lives and irreparably injure the business interests of inhabitants of the complainant;

That the complainant is without remedy except in a court of equity, and

That it prays for an injunction restraining the defendants from doing the acts herein alleged.

In a supplemental bill of complaint, made subsequent to the opening of the drainage canal, the complainant alleged—

That the water of the canal had destroyed the value of the water of the Mississippi for drinking and domestic purposes, and had caused much sickness to persons living along the banks of said river in the State of Missouri;

That, under the law authorizing the construction of the canal, it was required that said sewage be diluted with not less than 20,000 cubic feet of water per minute for each 1,000 inhabitants of the sanitary district, and

That the defendants had reduced this amount to about 10,000 cubic feet per 1,000 inhabitants and, acting under the authority of the Secretary of War, proposed thereafter to limit the maximum dilution to that amount.

ANSWER OF THE DEFENDANTS.

The State of Illinois united with the codefendant in general admissions, denials, and allegations, and further contended that the sanitary district was not subject to the control of the executive department of the State of Illinois, and that all acts of the State and its executive department were performed prior to January 17, 1900, the date at which the complainant moved for permission to file this bill of complaint.

The sanitary district admitted the character of the complainant, its population and location with reference to Mississippi River, and the jurisdiction of each party with reference to said stream as alleged in the bill of complaint.

It further admitted that Illinois River empties into the Mississippi at a point above the city of St. Louis, and that a large population of said plaintiff relies on the waters of Mississippi River for their water supply for domestic, agricultural, and manufacturing purposes.

In reference to the question as to whether or not the said waters are indispensable to the life, health, and happiness of the said inhabitants, and whether or not said inhabitants are compelled to use such

waters for the aforesaid purposes, the defendant neither admitted nor denied, but left the complainant to make proof thereof.

The defendant admitted the passage of the law creating the sanitary district and all the complainant's allegations with reference to the geographic situation of Lake Michigan and of the various rivers and the canal forming the drainage system of the defendant.

The construction of the drainage canal as alleged in the bill of complaint was admitted, and the allegation that the sewage of the district has been caused to flow through such canal into Desplaines River.

The defendant denied that the sewage of said district flows into Chicago River and Lake Michigan, but averred that the greater portion thereof had for many years been discharged into Desplaines and Illinois rivers, the same having been pumped from Chicago River into the Illinois and Michigan Canal and through this conducted to said rivers.

It was further denied that large quantities of sewage matter had accumulated upon the beds of Chicago River and Lake Michigan, and further that the plans adopted would loosen such matter and cause it to flow into Desplaines River.

It was further denied that the waters of the Mississippi will be poisoned and polluted by the completion of the plans above noted and that the adaptability of said waters for domestic and other uses will be destroyed.

It was further denied that the discharge of sewage through the canal will injure the property and business of the cities of the complainant or that it will create a direct and continuing nuisance.

The defendant averred that the turning into Desplaines River of such sewage, together with 300,000 cubic feet per minute of the pure water of Lake Michigan, will greatly improve the quality of the water of the Mississippi.

The defendant made numerous allegations concerning the discharge by means of pumps of nearly all the sewage of Chicago through the Illinois and Michigan Canal, and further alleged that the acts of the defendant with reference to the construction of the canal and the plans in relation thereto are open and notorious and largely matters of record.

That during the nine years since the institution of the work the defendant had expended more than $33,000,000.

That the complainant had notice of such work, and that said complainant, having delayed this complaint until the completion of said work, had been guilty of laches and was therefore estopped to further urge this cause.

It was further averred that the distance by water from Robey street, Chicago, to the mouth of Illinois River is 322 miles, and that

on the various tributaries that unite to form Illinois River and on the main stream there was a population of not less than 1,500,000, exclusive of the sanitary district of Chicago, and that a large number of cities drained into the said rivers, and that the sewage of said cities had for a great length of time flowed by way of said rivers to Mississippi River.

That Mississippi River and its tributaries form the natural drainage system of a vast region of country and that the additional amount of sewage discharged through the canal is trifling in amount as compared with the enormous volume received from cities on the Mississippi drainage area above St. Louis.

That by natural laws governing running water in large bodies the sewage was deprived of all its deleterious qualities by processes of vaporization, attrition, and chemical conversion.

In answer to the supplemental bill of complaint, the sanitary district admitted the opening of the canal, but denied that the sewage had polluted the waters of the Mississippi or that the same had or will hereafter cause sickness to persons living upon the banks of said river in the State of Missouri.

It was averred that the defendant would prove, if permitted, that the turning into Illinois River of said sewage, together with the pure waters of Lake Michigan, does not in any way impair the value of the waters of the Mississippi.

It was further averred that suburban towns and villages having a population of 50,000 discharged their sewage into Mississippi River opposite said city, which caused a much greater pollution of the waters of said river than can possibly be produced by the waters coming from Illinois River; that the natural flow of Mississippi and Missouri rivers, the latter entering a short distance above the city of St. Louis, caused a pressing of the Illinois waters upon the east bank of Mississippi River lying along Illinois River and prevented them from mixing with the waters flowing along the west bank of said stream and into the intake of the waterworks of the city of St. Louis.

WITNESSES AND COUNSEL.

The principal witnesses called to testify in behalf of the parties to this suit were as follows:

In behalf of the plaintiff: Benezette Williams, Amand Nicholas Ravold, Edward H. Keiser, William C. Teichmann, J. L. Van Ornum, George Chandler Whipple, William Thompson Sedgwick, Gardner Stewart Williams, George W. Fuller, Allen Hazen, Edward W. Saunders, Washington E. Fischel, Ludwig Bremer, Albert E. Taussig, Charles H. Goodman, Herbert E. Smith, John W. Alvord, and Ernest E. Lochridge.

In behalf of the defendants: John H. Long, F. Robert Zeit, Adolph Gehrmann, D. B. Bisbee, Arthur W. Palmer, Thomas J. Burrill, Edwin Oakes Jordan, Henry L. Russell, Isham Randolph, Ludwig Hektoen, E. G. Hastings, Erastus G. Smith, Jacob A. Harman, Robert Spurr Weston, William Pitt Mason, Rudolph Hering, George Dock, Lewellys F. Barker, Theobald Smith, Victor C. Vaughan, Leonard P. Kinnicutt, William S. Thayer, and John W. Hill.

The principal counsel participating in the examination were the following:

In behalf of the plaintiff: Edward C. Crow, attorney-general of the State of Missouri; Samuel B. Jeffries and William F. Woerner, of counsel.

In behalf of the defendants: H. J. Hamlin, attorney-general of the State of Illinois; James Todd, solicitor for the sanitary district of Chicago; William M. Springer, John G. Drennan, and W. C. Johns, of counsel.

The examination was conducted before Frank S. Bright, commissioner of the Supreme Court of the United States.

TYPHOID FEVER IN THE MISSISSIPPI VALLEY.

During the course of the testimony there were introduced, through various witnesses, the records of deaths from typhoid fever at numerous cities in the Mississippi basin above St. Louis. In order that this record may be more comprehensive, the figures have been combined in the following table, and will be referred to in connection with the deductions of certain witnesses for both parties to the suit.

TABLE 1.—*Deaths from typhoid fever in designated cities in Mississippi basin above St. Louis, Mo., 1893–1902.*

	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	Population in 1900.
Mississippi basin above mouth of Illinois River:											
Minneapolis, Minn.	134	107	88	60	148	86	71	79	121	66	202,718
St. Paul, Minn.	51	32	38	37	22	43	30	36	24	23	163,065
Dubuque, Iowa	6	6	12	8	12	10	12	7	8	10	36,297
Burlington, Iowa	8	10	8	13	3	4	8	13	12	11	23,201
Keokuk, Iowa	8	14	3	3	7	10	9	10	4	7	14,675
Des Moines, Iowa	22	29	30	14	20	17	13	7	22	21	62,139
Quincy, Ill.	22	33	24	13	15	6	7	9	12	18	36,252
Hannibal, Mo.	7	7	6	8	10	8	4	3	3	2	12,781
Davenport, Iowa	5	6	4	3	5	2	12	14	11	11	25,274
Rock Island, Ill.	15	13	3	13	.....	.....	10	14	28	5	19,493
Moline, Ill.	7	9	8	11	3	5	20	22	16	7	17,560
Winona, Minn.	2	2	1	2	2	2	5	5	1	4	.....
Red Wing, Minn.	5	2	2	3	0	4	0	3	2	3	.....
Fort Madison, Iowa	.....	.....	.....	.....	.....	.....	.....	5	.....	1	.....
La Crosse, Wis.	15	2	5	0	3	8	7	7	5	4	.....
Louisiana, Mo.	.....	.....	.....	.....	.....	.....	.....	4	2	7	.....
Clinton, Iowa	10	5	3	7	5	7	7	10	12	5	.....
Muscatine, Iowa	4	8	5	5	2	25	2	13	8	5	.....
	321	285	240	200	257	237	217	271	291	210	.....

TABLE 1.—*Deaths from typhoid fever in designated cities in Mississippi basin above St. Louis, Mo., 1893–1902*—Continued.

	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.	Population in 1900.
Missouri River basin:											
Lincoln, Nebr.	33	21	23	15	14	12	13	4	13	10	40,169
Omaha, Nebr.	22	40	29	18	22	32	26	24	23	20	102,555
Council Bluffs, Iowa	5	7	6	8	8	6	8	11	6	8	25,802
St. Joseph, Mo.	20	22	31	19	15	19	37	20	12	13	102,979
Kansas City, Mo.	59	37	34	29	38	49	52	49	58	58	163,752
St. Charles, Mo.	.....	.....	.....	.....	.....	.....	22	5	6	14	.....
	139	127	123	89	97	118	158	113	118	123	.....
Illinois River basin:											
Chicago, Ill.	670	491	518	751	437	636	442	339	509	801	[a]1,500,000
Joliet, Ill.	12	14	0	12	12	15	15	13	13	21	29,353
Ottawa, Ill.	2	5	2	2	4	4	3	3	5	2	10,588
Elgin, Ill.	5	3	5	14	.....	4	5	15	15	8	22,433
Aurora, Ill.	6	12	19	10	5	10	4	17	11	2	24,147
Peoria, Ill.	.....	.....	.....	13	18	18	12	33	15	18	56,100
Pekin, Ill.	.....	.....	.....	.....	.....	.....	.....	2	1	2	8,420
Decatur, Ill.	5	7	2	1	7	5	7	11	5	4	20,754
Bloomington, Ill.	12	14	15	9	10	10	9	15	9	15	23,286
Springfield, Ill.	.....	.....	.....	.....	.....	.....	.....	20	10	8	34,159
Havana, Ill.	3	7	2	5	.....	.....	.....	.....	1	2	.....
	45	62	45	66	56	66	55	129	85	82	.....
St. Louis, Mo.	215	178	106	106	125	95	130	168	198	222	575,238

[a] Tributary to Chicago drainage canal.

TESTIMONY FOR PLAINTIFF.

BENEZETTE WILLIAMS.

DIRECT EXAMINATION.

Benezette Williams, a consulting engineer of Chicago, formerly chief engineer of the sanitary district, and for a number of years connected with the sewer department of that city, was called as a witness in behalf of the complainant and testified to certain geographic and engineering facts concerning the city of Chicago, the sanitary district, and the drainage canal. The examination was somewhat digressive and the witness was frequently not allowed to finish his testimony concerning one point before he was diverted to another; therefore the following paragraphs are presented without reference to the order in which they were related by the witness:

The city of Chicago has an area of about 190.6 square miles and extends along the southwestern shore of Lake Michigan for about 20 miles. The eastern boundary is therefore the lake itself, except for a distance of 4½ miles where it is coincident with the western boundary of Indiana; the southern boundary is a line running at right angles from the State boundary; the northern boundary is parallel to and 24 miles distant from the southern boundary.[a]

Chicago lies very low, the elevation running from lake level to 25 feet above. During the construction of the city it was necessary to

[a] The western boundary is irregular; in general it is at a distance of 8 miles from the eastern boundary.—M. O. L.

raise the grades in order to cover the sewers and elevate the city out of the mire. A considerable portion of the city has been built out into the lake, the mouth of Chicago River, for example, being more than one-half mile farther out than formerly. As a whole, the city lies too low to afford sufficient gradient for the discharge of the sewers by gravity, and therefore trunk sewers have been laid below the lake level and pumps have been installed to raise the sewage from them.

One of the most important, as well as the most troublesome natural features about Chicago is Chicago River. The main stream was originally not over a mile long from the lake back to the confluence of two forks. The northern fork (called North Branch) is the larger of the two, rises in Wisconsin, and runs in a southeasterly direction across the northern portion of the city. The southern fork (called South Branch) divides at a distance of about 5 miles from the lake into two forks, which are locally known as West Fork and South Fork. South Fork drains a very small territory and originally was merely a ditch, dry except during floods. West Fork also drains a small territory, the area adjoining that of Desplaines River. Formerly, during floods, Desplaines River would break over the divide and come down West Fork into Lake Michigan, making the fork at such times a comparatively large stream. Throughout the greater length of Chicago River and its branches in the city the channel has been dredged and docked for commercial purposes, and a considerable depth of water is maintained.

From the time of the initial development of Chicago the river has been commonly utilized for the discharge of sewage. With the growth of the city the danger occasioned by this practice became more and more acute until it was necessary to provide means for purifying the stream. The readiest means at hand was the dilution of the river water by that from Lake Michigan, and this was accomplished for several decades, both by the actual pumping of the lake water into the river through conduits and by the pumping of river water into the Illinois and Michigan Canal, allowing the lake water to take the place of that so discharged. The character of these conduits and pumping works is briefly as follows:

In 1879 a 12-foot conduit was completed, running from the lake along Fullerton avenue to North Branch. The pumps there installed had a working capacity of 15,000 cubic feet per minute. This amount of fresh water from the lake had the effect of flushing the impurities gathered in North Branch either into the lake or down South Branch, according as the current ran toward one place or the other.

Another conduit was excavated along Lawrence avenue, circular in cross section and 16 feet in diameter. The conduit had not been completed at the date of the testimony. It was designed to take

away by means of a system of intercepting sewers the sewage then discharged into the lake along the north shore, as well as to supply water from the lake to North Branch.

South Fork of South Branch has its origin about 3 miles south of its confluence with South Branch and was at first merely a storm-water drain. At this time it is dredged for shipping purposes and extends to the Chicago stock yards. A conduit has been built into what is known as the east arm of South Fork, an arm merely dredged out for docks. This conduit, 20 feet in diameter, with a capacity of 120,000 cubic feet per minute, was constructed to divert the sewage entering the lake along the south shore and to supply fresh water to flush South Fork.

The city of Chicago more than thirty years ago established a pumping station at the head of South Branch near Ashland avenue and Twenty-sixth street for the purpose of turning the foul water of the stream into the Illinois and Michigan Canal, thereby relieving the river of much of its impurity. This plan was efficient for a time, but with the unexampled growth of the city and the consequent increasing foulness of Chicago River the pumping necessary to the purification of the river soon increased beyond the capacity of the plant. These pumps were operated by the city until 1900 and had the effect of reversing the normal course of the current in South Branch. In the year mentioned, however, the works were turned over to the sanitary district of Chicago and finally to the commissioners of the Illinois and Michigan Canal. At present they are used only for keeping up the level of the canal for navigation purposes. The Chicago drainage canal was the result of the increased pollution of Chicago River and was built to divert all the sewage of the city from the lake into Desplaines River.

The Chicago drainage canal begins at Robey street, Chicago, about one-fourth of a mile north of Thirty-first street, and is parallel with the old Illinois and Michigan Canal as far as Lemont—that is, to the range line just east of Summit. This stretch of the canal is 41,100 feet in length. The elevation of the bottom of the channel at Robey street is 24.45 feet below Chicago datum, this datum being the lake level at low-water mark in 1847. From Robey street to Willow Springs, a distance of 13.2 miles, the grade is 1 foot in 40,000, so that at Willow Springs the elevation of the canal bottom is −26.2 feet. The section from Robey street to the range line at Summit is dug in glacial drift 110 feet wide on the bottom, with slopes of 2 to 1, making the width at water line about 200 feet. From the range line at Summit to Willow Springs the canal is in glacial drift except for a short distance, where it strikes some rock. The canal is built in the manner above described throughout this second stretch. From Willow Springs to a point within about 4,000 feet of the controlling works at

Lockport the channel is 160 feet wide on the bottom, with vertical sides formed by excavating the rock which extended most of the distance between the two points. Along this stretch there is a fall of 1 foot in 20,000. At a point within 4,000 feet of the controlling works the canal widens out in fan shape, and just above the works the width becomes considerable. The grade is maintained the same, the elevation of the bottom at the works being −30.1 feet, which gives a total fall of the canal between Robey street and the controlling works of 5.55 feet. The distance between the two points is 28.01 miles.

As originally designed, according to the prescription of law, the canal is intended to carry 600,000 cubic feet per minute, with the water in the lake as datum. This capacity was provided for in all rock excavations, but in the first section, between Robey street and Summit, the canal was made smaller, with a view to widening in the future as the demand should arise. The canal was commenced in the fall of 1892, and it was accepted by the governor of Illinois January 17, 1900.

The flow from the canal to Desplaines River during the early periods is as follows:

Flow from Chicago drainage canal to Desplaines River, January 20, 1900, to March 16, 1901.

	Cubic feet per minute
January 20 to March 31, 1900	179,7[illegible]
March 31 to June 30, 1900	211,5[illegible]
June 30 to September 29, 1900	210,[illegible]
September 29 to December 29, 1900	250,6[illegible]
December 29, 1900, to March 31, 1901	303,7[illegible]
Maximum flow, March 16, 1901	356,7[illegible]

The rate of flow in the canal, as reported June 20, 1900, by Major Willard, United States Engineer Corps, was as follows: Whenever there was a discharge of 150,000 to 210,000 cubic feet per minute the average velocity was 1.79 feet per second, or 1.22 miles per hour; when the discharge was from 270,000 to 310,000 cubic feet per minute the average velocity was 2.72 feet per second, or 1.85 miles per hour.

For the purpose of showing the population tributary to Chicago River in the city, and thereby indicating the great amount of polluted matter discharged into it, the witness stated that he had made for the whole city a distribution of the population according to the points of watercourse to which it is tributary and had represented that distribution of the city into districts by a map, which he introduced in evidence. These districts are numbered from 1 to 12, inclusive, and were fixed according to the sewer map of Chicago, showing the main sewers, each district being tributary to one of them. Based on these districts, the total population of the sanitary district—that is, north of Eighty-seventh street—was, in 1900, 1,639,546. Consolidating cer-

tain districts in accordance with the drainage system, the witness found that the population tributary to the main portion of Chicago River and to South Branch was 791,677; that tributary to the lake on the south shore, which the witness explained will ultimately be discharged into South Branch, was 175,182; tributary to South Fork of South Branch, 282,655; tributary to West Fork within the city limits, 74,899; tributary to North Branch, 555,789; tributary to the lake on the north shore, 28,878. Aside from the districts here enumerated there was in the southern part of the sanitary district a population of 18,827 that had not up to that time been provided with a sewerage system; and in what is known as the Calumet district, lying south of Eighty-seventh street and discharging into Calumet River, there was a population of 70,636.

Summarizing these, the witness stated that there drained into the main river, South Branch, and various tributaries a total population of 1,705,020. To this there would ultimately be added, through the Lawrence avenue and Thirty-ninth street conduits, under construction, the drainage from a population of 204,060. After these conduits are put into operation, the sewage intercepted and turned into the river, there will be distributed directly into the main river, South Branch, and the drainage canal the sewage from a population of 800,829; into South Fork that from 476,664; into West Fork that from 74,899; and into North Branch that from 584,664. The foregoing figures are based on the school census, which was in excess of the Federal census by about 16 per cent. Witness stated that the sewage from about 200,000 people was discharged directly into Lake Michigan.

CROSS-EXAMINATION.

On cross-examination the witness stated that the pumps which were used in South Branch of Chicago River to deliver polluted water to the Illinois and Michigan Canal had operated most of the time since their installation up to 1900, or for a period of about thirty years, usually at their full capacity, not far from 45,000 cubic feet per minute, and that this water eventually reached Illinois River through the foot of the canal at La Salle and from various waste weirs between the two points.

REDIRECT EXAMINATION.

The testimony of the witness was closed with a description of the controlling works of the Chicago drainage canal at Lockport. He stated that at these works there were seven sluice gates operated by mechanical appliances, each gate having an opening 30 feet wide. They are held as a reserve until the time comes when they will be needed. The main appliance relied on at present for controlling the

flow from the canal is known as the Bear Trap dam; it is 160 feet long and has a vertical oscillation of 17 feet. This dam is a steel caisson the upper edge of which points upstream and can be lowered or raised by water power. When the dam was completely lowered there would pass over it an amount of water which the witness estimated as from 800,000 to 1,000,000 cubic feet per minute, or more than equal to the capacity of the intake of the canal at Chicago River, while when the dam is raised to its maximum height, the flow of water from the canal can be shut off completely.

The testimony of this witness occupies pages 480 to 543 of the record.

J. L. VAN ORNUM.

J. L. Van Ornum, called as a witness in behalf of the complainant, qualified by making the following statements: He is a civil engineer by profession, having graduated from the University of Wisconsin in 1888; for about ten years thereafter was engaged in the general practice of the profession of civil engineering in different parts of the country, the work including municipal, railway, and river and harbor investigations, together with that on the Mexican boundary survey; at the time of testimony and during four years previous thereto had been professor of civil engineering at Washington University, St. Louis, Mo. (1733–1734)[a].

The witness stated that in March, 1903, he was engaged by the city of St. Louis to determine the time required for water to flow from Chicago, through the drainage canal and Desplaines, Illinois, and Mississippi rivers, down to the water intake at Chain of Rocks. The investigation was divided into three sections; one covered the distance from Chicago to Peoria, the second from Peoria to Grafton, and the third from Grafton to Chain of Rocks. It had been the intention to carry on the work in all these sections simultaneously and continue the observations day and night, but this was found impracticable by reason of adverse conditions which made it impossible to follow the floats at night. Therefore they were taken out of the water at night and replaced in the same positions on the following morning. (1734.)

The floats were of the submerged type, the lower portion consisting of metal-plate vanes set into each other in such a way that in whatever direction the current should turn there would be a considerable area exposed. Each plate was 12 by 12 inches in area. It was connected to the buoyant part of a float by a chain, the length of which varied in different floats according to the depth of the water in which it was used. The part of the float which gave buoyancy consisted of

[a] Figures in parentheses throughout this paper refer to pages of the official record of testimony.

two cones with bases superimposed at the periphery. The cones had a diameter at the base of 12 inches, while the axis of the double cone was about 8 inches in length, the idea being to so regulate this size that the buoyant part of the submerged float would be made to sink to about half its height by the weight which it was supporting. Extending down through the center of this cone was a cylindrical tube into which was set a stiff wire which supported a metal flag 4 by 4 inches. This flag was numbered and painted a certain color in order that the observers might readily distinguish the various floats. The whole idea of float construction was to get as closely as practicable the velocity of water on and below the surface, rather than merely that at the surface, so that there might be derived from the observations a more accurate idea of the velocities of the stream. The length of the chains supporting the vanes was set at 1, 2, and 3 feet for those used on Illinois River, while those on Mississippi River were regulated to 2, 4, and 6 feet. (1735–1736.)

The testimony of the witness with reference to the intervals noted during the investiagtion is collected in Table 2. (1737–1742.)

TABLE 2.—*Rate of flow of Chicago drainage canal and Desplaines, Illinois, and Mississippi rivers from Chicago to St. Louis, March, 1903.*

FIRST SECTION—CHICAGO TO PEORIA.

Day.	Measuring points.	Interval.		Remarks.
		Hr.	*min.*	
	Head of canal			
	Western Avenue Bridge, Chicago		40	Estimated.
15	C. and C. T. Ry. bridge	7	59	
16-17	Cook County line	19	4	
16	Desplaines River at Bear Trap dam	6	43	34 hours 26 minutes in canal.
16	Joliet, Ill	2	15	River at flood stage.
17	Designated flag station	3	36	
18	1 mile above Dupage River	3	6	
19	Morris	7	54	
20	Seneca	5	2	
20	Marseilles	2	15	
21	Ottawa	2	7	
21	Utica	3	36	
22	La Salle	2	28	
22	Peru		58	
22	Marquette	5	6	
22	Depue	1	1	
23	Hennepin	4	15	
23	Twin Island	7	5	
[a]24				
25	Henry	8	36	
25	Flag station at small island	1	49	
26	Chillicothe	11	18	
25	Rome	2	26	Observations by special party sent ahead.
25	Blazed tree on bank	9	48	
26	Peoria main highway	17	45	Lockport to Peoria, 102 hours 26 minutes.

[a] No observation by reason of storm.

TABLE 2.—*Rate of flow of Chicago drainage canal and Desplaines, Illinois, and Mississippi rivers from Chicago to St. Louis, March 1903*—Continued.

SECOND SECTION—PEORIA TO GRAFTON.

Day.	Measuring point.	Interval.		Remarks.
		Hr.	*min.*	
	Peoria			
14	Pekin	4	30	River at flood stage.
15	Kingston	3	17	
15	Banner	7	43	
16	Liverpool	8	58	
17	Havana	10	40	
18	Sheldons Grove	10	37	
19	Beardstown	10	51	
20	Lagrange	6	22	
20	Flag station on tree	3	33	
21	Naples	5	19	
18	Florence	4	15	Observations by special party sent ahead.
18	Bedford	3	35	
19	Pearl	2	45	
19	Kampsville	5	15	
19	Designated beacon	1	40	
20	Hardin	3	50	
20	Government light	5	15	
21	Grafton	4	2	Peoria to Grafton, 102 hours 27 minutes.

THIRD SECTION—GRAFTON TO CHAIN OF ROCKS.

	Grafton			
18	Alton	6	36	River at half stage.
18	Intake tower, Chain of Rocks	4	34	Grafton to Chain of Rocks, 11 hours 10 minutes.

Total time, Chicago to St. Louis, 10 days, 10 hours, 29 minutes.

The witness stated that although the work was all done under his supervision, none of it was conducted personally except that between Grafton and Chain of Rocks. The assistant engineers employed to make the observations between Chicago and Grafton submitted field notes properly certified. These notes included records of velocity and direction of wind, velocity of floats, condition of the weather and stream, the general course taken by the floats, and every incident or fact having any bearing on the work. The instructions given to assistant engineers making the observations were that the floats should be placed in the stream along the cross section and allowed to take their own course. Whenever one of the floats would go ashore or become entangled in a snag, it would be removed and carried forward to the position of the most advanced float. (1743–1744.)

In reply to a question concerning the side of the river taken by the floats during the observations made from Grafton to Chain of Rocks, the witness stated that the floats were placed in the lower end of Illinois River in such a way that they went across the river, one in the center, one about half way from the center to the right bank, and the third half way from the center to the left bank. As they floated into Mississippi River they moved closer to the Illinois shore, and from Illinois River to a point below the mouth of the Missouri they were more or less close to the Illinois shore. At a point about 2 miles above

the waterworks intake, the floats were fairly close to the Illinois shore, perhaps about 50 feet from it, but from this point down to the intake the floats rapidly left the Illinois shore, reaching the middle of Mississippi River, and finally passing the intake between it and the Missouri shore. (1745–1746.)

On being recalled to the witness stand, Professor Van Ornum testified that he had taken samples from Mississippi and Missouri rivers and sent the same to George C. Whipple at Brooklyn for examination. The samples were taken along the sections across the rivers as follows: Section B in Missouri River above its confluence with the Mississippi; section M in Mississippi River above the mouth of the Missouri; section C in Mississippi River below the mouth of the Missouri; and section I in Mississippi River close to the intake at Chain of Rocks. A chart showing these locations was presented and discussed. The samples taken were numbered from 1 to the highest number, No. 1 always being toward the right bank of the river. Eight points were located along each of sections M and C, twelve along section I, and three along section B. At each sampling point on section B one sample was taken at a depth of 10 feet; at each point on sections C and I three samples were taken at depths of 6 inches, 10 feet, and 30 feet or at the bottom, being designated, according to the depth of the water, a, b, and c, respectively. (1882–1884.)

AMAND NICHOLAS RAVOLD.

DIRECT EXAMINATION.

Dr. Amand Nicholas Ravold was called as a witness on behalf of the complainant and qualified as an expert by stating that he had been a practicing physician since 1881 and a professional bacteriologist since 1885. From 1887 he had been connected with the medical department of Washington University, during most of which period he had held the professorship of bacteriology. In 1894 he entered the employ of the health department of the city of St. Louis, as consulting bacteriologist. The testimony occupies pages 2–480, volume 1 of the record.

After relating at some length the history of bacteriology and its development and discussing briefly various epidemic diseases and methods of sewage disposal, the witness was directed to the subject in hand. (7 et seq.)

The bacteriological investigation carried on by the city of St. Louis to determine the effect of the water from the Chicago drainage canal was divided into three periods, the first extending from August to December, 1899; the second from January to December, 1900, and the third from September to November, 1901, each inclusive. Besides this, from January to April, 1902, the witness engaged in special investigations, and from June to September of the same year carried on

experiments to determine the longevity of *Bacillus typhosus* in water under various conditions. The witness further stated that all methods used in these investigations conformed with the recommendations of the committee on standard methods in water analyses appointed by the American Public Health Association, except such special procedure as he had devised during the investigations for original work. (57–76.)

Previous to the beginning of this investigation a temporary bacteriological laboratory was established at Chain of Rocks, and August 10, 1899, numerous samples of the water were taken from the river in the intake and in the uptake, which is at the end of the 1,500 feet of channel running from the intake tower to the Missouri shore. As the results are simply preliminary in character and not especially significant, the tables will not be given in this review. It is sufficient to state that from August 10 to September 25, 1899, the number of bacteria in Mississippi River above the intake varied from 275 to 3,600 per cubic centimeter; the four water samples taken at the intake from August 10 to 23 showed a content of 375 to 950 bacteria per cubic centimeter, and in the samples taken at the uptake from August 10 to September 11 the number of bacteria varied from 150 to 1,500. The results, as a whole, show an unmistakable decrease in the number of bacteria between the river above the intake and the end of the tunnel at the shore. (76–81.)

Following this five series of samples were taken from a boat along Illinois, Mississippi, and Missouri rivers at various points, the results of which are not here recorded. (81–85.)

Commencing January 23, 1900, six days after the opening of the Chicago drainage canal, a systematic bacteriological survey was started, daily samples being taken from the following points:

Lake Michigan.
Chicago drainage canal.
Desplaines River at Joliet and Lockport.
Illinois River at Peoria, Beardstown, and Grafton.
Mississippi River at Grafton, Alton, and Hartford.
Missouri River at Fort Bellefontaine.
Mississippi River opposite St. Louis water-supply intake at three points on cross section, Missouri shore, midriver, and Illinois shore.

These samples were transported to St. Louis, and throughout the remainder of the year the number of bacteria per cubic centimeter and the presence or absence of *Bacillus coli communis* were determined. The results of the determinations on Lake Michigan samples are given in Table 3. (93–96.)

TABLE 3.—*Bacteriological examination of seventeen samples of water from Lake Michigan in 1900.*

Date.	Place.	Bacteria per cubic centimeter.	B. coli communis.[a]
July 23, 11.45 a. m	4-mile crib	1,600	+
July 30, 11.30 a. m	Carter Harrison crib	12,300	+
Aug. 9, 4.00 p. m	10 miles out from Chicago	16,300	+
Aug. 31, 10.30 a. m	Carter Harrison crib	21,400	+
Sept. 7, 11.30 a. m	Lake View crib	5,200	–
Sept. 15, 10.30 a. m	2-mile crib	909,700	+
Sept. 15, 11.45 a. m	3-mile crib	111,500	+
Sept. 22, 2.00 p. m	2-mile crib	61,000	–
Sept. 22, 11.15 a. m	68th street crib	44,000	–
Oct. 11, 12.15 p. m	2-mile crib	1,100	–
Oct. 11, 11.30 a. m	3-mile crib	1,000	+
Oct. 19, 11.00 a. m	2-mile crib	4,400	+
Oct. 19, 10.30 a. m	3-mile crib	1,100	–
Oct. 26, 11.45 a. m	4-mile crib	90,000	–
Oct. 26, 12.30 a. m	68th street crib	157,500	–
Nov. 9, 11.30 a. m	do	3,300	–
Nov. 9, 11.00 a. m	4-mile crib	2,900	–

[a] + indicates presence of *B. coli communis;* – indicates absence of *B. coli communis.*

The witness then read into the record the results of the daily examinations made at the various other points above mentioned. The complete statement occupies pages 100–211, inclusive, of the official record of testimony. The results, condensed into weekly averages with the per cent of samples containing *B. coli communis*, are included in Table 4.

In connection with report of these investigations the witness discussed the work of identification of bacterial flora in samples taken from seven points. The results are combined in Table 5.

TABLE 4.—*Weekly averages of results of bacteriological examinations January 23 to October 9, 1900, on samples taken from designated points.*

[Numbers of bacteria expressed in thousands per cubic centimeter; of *B. coli communis* in per cent.]

Week beginning—	Drainage canal at Lockport.		Desplaines River at Joliet.		Illinois River 3 miles above Peoria.		Illinois River 3 miles above Grafton.		Mississippi River 3 miles above Grafton.		Mississippi River above Alton.		Mississippi River at Hartford.		Missouri River at Fort Bellefontaine.		Mississippi River at Chain of Rocks, Missouri shore.		Mississippi River at Chain of Rocks, intake tower.		Mississippi River at Chain of Rocks, Illinois shore.		Outlet of reservoir, St. Louis waterworks.		Tap in laboratory, St. Louis.	
	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.
Jan. 23	.....	.....	.....	.....	170	100	116	40	41	57	120	40	88	25	213	50	240	25	154	60	155	50	49.8	67	.....	.....
Jan. 30	.....	.....	.....	.....	360	71	189	30	46	20	115	0	147	33	141	0	147	0	135	0	76	75	110	29	.....	.....
Feb. 6	.....	.....	.....	.....	91	57	258	33	43	30	100	0	106	0	63	0	58	0	75	0	106	0	28.3	0	.....	.....
Feb. 13	.....	.....	.....	.....	622	66	222	83	161	17	296	33	233	25	52	0	98	29	133	100	224	25	92.2	0	.....	.....
Feb. 20	.....	.....	.....	.....	378	66	222	71	105	33	250	29	267	83	70	0	77	50	112	66	192	100	106.3	33	.....	.....
Feb. 27	.....	.....	.....	.....	374	66	223	83	55.5	83	157	60	193	40	63	80	50.5	60	53	50	77	100	53.1	60	.....	.....
Mar. 6	1,010	80	2,792	71	210	43	268	43	125	71	215	43	209	14	176	43	177	75	177	33	174	100	69.8	29	.....	.....
Mar. 13	10,339	83	9,208	66	579	86	277	86	490	86	312	57	320	86	435	71	485	57	485	50	374	86	253	83	.....	.....
Mar. 20	16,233	57	13,308	86	536	83	204	57	434	66	156	57	228	71	271	43	315	57	512	57	254	43	349.5	71	.....	.....
Mar. 27	4,921	71	4,860	71	276	50	159	57	142	40	90	43	60.5	14	139	50	70	29	118	29	76	86	76.8	29	.....	.....
Apr. 3	2,490	100	5,602	86	310	43	143	71	37.5	0	59.5	29	58	43	140	29	76	57	118	43	47.5	14	41	43	.....	.....
Apr. 10	2,391	83	6,250	57	65	16	24	50	69	57	23.5	60	34	33	66	50	62.5	100	90	67	37	0	35.5	40	.....	.....
Apr. 17	621	71	934	71	65	43	9	71	18.5	57	9.5	43	16	71	49	57	21	57	37	57	14.5	71	84.7	71	.....	.....
Apr. 24	191	60	236	57	20	0	2.5	0	11	71	10	29	7.5	29	49	50	11.5	43	12	57	9	16	9.8	43	.....	.....
May 1	821	100	211	83	5	80	2.5	25	2	67	7	20	11.5	100	16.5	80	10.5	60	7	80	2.5	100	7.1	75	.....	.....
May 8	323	86	581	83	78	86	12.5	66	7	71	13.5	71	15.5	86	22	43	46	43	23.5	100	21.5	57	23.3	43	10.5	.....
May 15	140	71	354	30	462	30	6	43	6.5	57	16.	43	18	50	45.5	33	43	67	13.5	14	24	43	14.5	33	3.5	0
May 22	1,232	100	783	66	623	83	6	80	6.5	100	8	75	6	100	40.5	50	29.5	83	4	100	9	67	4.2	100	3.6	20
May 29	634	83	213	86	62	16	9.5	100	5.5	30	7	29	8	71	52	100	25	86	17	86	20	86	7.6	100	2.1	100
June 5	939	100	169	86	268	71	6.5	86	7	57	12.5	83	6	43	55.5	43	22.5	57	23.5	71	26	100	4.7	100	2.1	57
June 12	1,951	71	461	60	188	57	6	66	20	83	9	57	5	86	63.5	57	38.5	57	26.5	57	21.5	86	12.3	71	1.6	43
June 19	2,201	71	103	14	344	100	31	71	12	57	5.5	83	5	50	112	67	38.5	29	17	50	20.5	71	9.2	67	1.3	71
June 26	406	100	127	71	1,766	57	6.5	43	14.5	86	6	57	4.5	83	105	57	17	57	13	57	10.5	100	7.7	43	.9	100
July 3	1,225	100	121	100	304	66	17	86	15.5	83	3.5	83	3.5	57	29.5	86	1	86	14	80	10.5	100	4.8	100	1	100
July 10	181	71	90	71	791	100	15	71	24	43	3.5	29	7	100	27.5	100	20.5	100	19	71	8	57	5.4	86	.9	33
July 17	211	100	94	57	1,549	71	11.5	57	9	57	18	57	4	16	21	83	17.5	33	13	33	7.5	71	3.6	71	.6	67
July 24	479	83	168	43	335	100	18	100	12	86	5	43	3	50	10.5	57	10	71	7	83	4.5	57	2.7	100	1	86
July 31	346	100	450	100	489	100	9	100	20	100	2.5	100	1.5	100	10.5	100	6.5	100	4.5	100	5	100	3.6	100	1.1	100
Aug. 7	209	100	110	100	1,425	100	14	100	12.5	100	1	100	1.5	100	7	100	10	100	8.5	100	4.5	100	2.1	100	.8	100
Aug. 14	312	100	90	100	1,513	100	12.5	86	18	100	2	100	2	100	5.5	100	10	100	6.5	100	5.5	100	3.3	100	.8	100
Aug. 21	1,671	100	208	100	373	100	15.5	100	36.5	100	3	100	3.5	100	14	100	10.5	100	14	100	3.5	100	2.1	100	.9	100

TABLE 5.—*Bacterial flora in Desplaines, Illinois, Mississippi, and Missouri rivers at designated points.*

Species.	Desplaines River at Joliet.	Illinois River at Grafton.	Mississippi River at Grafton.	Mississippi River at Hartford.	Mississippi River at Chain of Rocks.	Missouri River at Fort Bellefontaine.	Laboratory tap, St. Louis.
Bacillus albus	+			+		+	
B. antenniformis					+	+	
B. aquatilis sulcatus I	+		+				
B. aquatilis sulcatus III			+	+		+	
B. aquatilis sulcatus V	+	+	+		+		
B. arborescens			+	+		+	+
B. aurescens		+	+	+	+	+	
B. aureus		+	+	+			
B. brunneus				+			
B. candicans							+
B. cereus		+	+	+	+	+	+
B. cloacæ	+	+	+	+	+	+	+
B. coli communis	+	+	+				+
B. delicatulus	+	+		+	+		+
B. desidiosus		+					+
B. fluorescens incognitus				+		+	
B. fluorescens liquefaciens			+	+	+	+	
B. fluorescens tenuis	+	+		+			+
B. fluorescens termo			+	+			
B. fulvus						+	+
B. helvolus	+		+	+	+		+
B. iridescens	+			+	+		
B. lactiviscosus	+	+	+		+		+
B. lactis erythrogenes				+			
B. liquefaciens	+	+	+			+	+
B. liquidus					+		
B. megaterium		+		+	+	+	+
B. mesentericus vulgatus		+		+			
B. nubulis						+	
B. ocraceus	+	+	+				
B. plicatus		+					
B. proteus mirabilis	+	+		+			+
B. proteus zenkeri	+		+	+		+	+
B. proteus zacarei		+					
B. rubefaciens							+
B. stellatus	+	+		+	+	+	+
B. subflavus		+					
B. subtilis					+		
B. superficialis	+			+			
B. ubiquitus		+			+		
B. ureæ		+					
B. viridis		+	+		+	+	+
Micrococcus cremoides							+
M. flavus liquefaciens							+
Sarcina lutea	+					+	+

A third series of examinations extended throughout the period from August 26 to December 1, 1901. The plan of procedure involved the establishment of temporary laboratories equipped with the necessary apparatus at the following points: Joliet, Ill., in charge of Dr. W. C. G. Kirchner; Peoria, Ill., in charge of Dr. William H. Rush; Grafton, Ill., in charge of Leon G. Tedesche; 1141 Market street, St. Louis, with five assistant bacteriologists under the charge of Dr. Ravold.

Samples were collected from the following points:

Sampling points, August 26 to December 1, 1901.

	Number of samples
Desplaines River at Lockport, above junction with drainage canal	[illegible]
Bear Trap dam, drainage canal	[illegible]
Illinois and Michigan canal, at Ninth Street Bridge, Lockport	[illegible]
Desplaines River at Ninth Street Bridge	[illegible]
Desplaines River at Ruby street, Joliet	[illegible]
Desplaines River at Brandon's bridge, Joliet	[illegible]
Illinois River at Averyville	[illegible]
Illinois River at railroad bridge, Pekin	[illegible]
Illinois River at Kingston, 3 miles below Pekin	[illegible]
Illinois River above Grafton	[illegible]
Mississippi River above Grafton	[illegible]
Mississippi River 1 mile above Alton	[illegible]
Mississippi River at Hartford	[illegible]
Missouri River at Bellefontaine	[illegible]
Mississippi River at Chain of Rocks, near Illinois shore	[illegible]
Mississippi River at Chain of Rocks, near Missouri shore	[illegible]
Mississippi River at intake tower	[illegible]
Reservoir at Chain of Rocks	[illegible]
Reservoir at Bissells Point	[illegible]
Laboratory tap, 1141 Market street, St. Louis	[illegible]
Tap at residence 5946 Garfield avenue, St. Louis	[illegible]

Besides the above, seven samples were collected from Illinois River at Lasalle, and twenty-four at Beardstown. These samples were sent to Peoria.

The witness explained that the purpose of taking the series of samples from a tap on Garfield avenue, St. Louis, was to show the difference in the condition of the water in the high service from that in the low. In addition to the seventy-hours sedimentation period afforded by the reservoirs at Chain of Rocks, the water diverted to the low service had the benefit of further storage in the reservoirs at Bissells Point. No further sedimentation period is afforded to the high service after leaving Chain of Rocks, but the effect of the long distance traveled by the water in the mains must be taken into account. Between the Chain of Rocks reservoirs and the Garfield avenue tap, 10 miles of pipe intervene, 6 miles of this lying between the reservoirs and the Compton Hill standpipe, and 4 miles between the standpipe and the Garfield avenue house.

The results of the third series of examinations were then read into the record by Dr. Ravold, and are reported on pages 222–275, inclusive. Table 6 contains the weekly averages of these determinations, together with the proportion of samples in each week containing *Bacillus coli communis*. These results are fairly representative of the daily figures and may be accepted in connection with all interpretations necessary to this testimony without important error.

TABLE 6.—*Weekly averages of results of bacteriological examinations, September 14 to November 30, 1901, on samples from designated points.*

Numbers of bacteria expressed in thousands per cubic centimeter; of *B. coli communis* in per cent.]

Week beginning—	Desplaines River above junction with Chicago drainage canal.		Bear Trap dam, Chicago drainage canal, Lockport.		Illinois and Michigan Canal at Ninth Street Bridge, Lockport		Desplaines River at Ninth Street Bridge, Lockport.		Desplaines River at Ruby street, Joliet.		Desplaines River at Brandon's bridge, Joliet.		Illinois River, 3 miles above Peoria	
	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.
Sept. 21	.....	.....	950	50	496	50	.....	.....	471	100	344	.....	.....	.....
Sept. 28	.....	.....	824	60	282	60	84	50	317	67	221	100	1.74	75
Oct. 5	42.3	20	487	75	665	50	317	25	224	100	442	100	.34	86
Oct. 12	4.2	40	764	60	1,077	33	366	25	581	83	69	67	1.16	100
Oct. 19	25.3	60	348	100	532	33	193	100	453	100	343	75	.27	86
Oct. 26	1.7	0	371	.....	1,080	.....	284	25	438	.....	346	.....	.66	71
Nov. 2	4.2	.....	533	.....	.....	.....	621	.....	249	.....	200	.....	.30	86
Nov. 9	2.0	.....	495	.....	.....	.....	441	.....	274	.....	299	.....	1.6	86
Nov. 16	4.0	.....	3,429	.....	.....	.....	3,572	.....	2,153	.....	210	.....	3.2	71
Nov. 23	4.2	.....	5,000	.....	.....	.....	6,000	.....	2,990	.....	3,045	.....	3.6	100

Week beginning—	Illinois River above railroad bridge at Pekin.		Illinois River at Kingston, 3 miles below Pekin.		Illinois River above Grafton.		Mississippi River, 2 miles above Grafton.		Mississippi River, 1 mile above Alton.		Mississippi River opposite Hartford.		Missouri River opposite Fort Bellefontaine.	
	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.
Sept. 28	36.5	100	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Oct. 5	20.4	100	387	100	1.4	57	0.82	29	0.56	100	0.74	100	11.1	100
Oct. 12	202	100	385	100	1.1	57	.79	71	.67	100	1.5	100	31.8	100
Oct. 19	81.7	100	221	100	2.1	43	.68	0	1.6	100	2.6	86	37.9	71
Oct. 26	9.2	71	481	100	2.6	57	.68	43	1.9	100	3.5	57	33.6	100
Nov. 2	5	100	275	86	7.1	43	1.2	43	1	50	2.5	50	21.7	75
Nov. 9	7.0	100	41	100	1.8	14	.99	71	1.5	86	3.5	71	49.2	86
Nov. 16	4.3	100	21.1	100	4.8	29	2.7	57	1.5	57	1.5	29	30.4	50
Nov. 23	3.3	.....	15.8	.....	3.7	.....	5.3	100	2.2	43	4.9	50	53.3	100

Week beginning—	Mississippi River at Chain of Rocks, near Illinois shore.		Mississippi River at Chain of Rocks, near Missouri shore.		Mississippi River at intake tower, Chain of Rocks.		Reservoir at Chain of Rocks.		Reservoir at Bissells Point.		Laboratory tap, 1141 Market street, St. Louis.		Tap at residence, 5946 Garfield avenue, St. Louis.	
	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.	Bacteria.	B. coli communis.
Sept. 14	0.59	67	1.1	75	1.8	50	0.46	67	0.14	.....	0.61	50	.....	.....
Sept. 21	5.3	86	3.5	67	3.5	83	1.2	83	.47	83	.34	100	.....	.....
Sept. 28	1.9	83	4.3	100	4.7	83	2.2	100	.49	67	.42	67	.....	.....
Oct. 5	8.5	100	7.7	100	6.8	83	1.75	100	.67	100	.91	100	0.31	86
Oct. 12	2.1	100	10.5	86	14.5	86	3.0	100	.63	86	.94	100	.38	100
Oct. 19	2.7	86	33.1	100	40	86	5.6	100	1.98	100	2.3	100	.53	100
Oct. 26	1.7	100	25.5	100	34.9	100	7.4	100	1.4	86	1.9	100	.40	100
Nov. 2	3.2	50	17.0	75	23.5	75	5.8	100	2.3	100	1.1	43	3.1	100
Nov. 9	2.4	86	40.9	86	45	86	7.1	100	2.8	100	2.5	86	3.9	100
Nov. 16	2.2	86	52	71	53.7	57	10	100	2.6	100	3.2	71	2.9	83
Nov. 23	5.2	71	32.9	100	39.2	86	7.8	71	2.9	83	2.9	80	1	100

Summing up the results of the third period of examination, the witness stated the percentage of samples taken at the various points along Mississippi River below Illinois River in which *Bacillus coli communis* was found, as shown in Table 7. (275–277.)

TABLE 7.—*Proportion of samples of water from designated points in which Bacillus coli communis was found, September to November, 1901.*

Sampling point.	September.	October.	November.	Average.
Mississippi River at Alton	.....	100	77	[illegible]
Mississippi River at Hartford	.....	86.4	56	[illegible]
Missouri River at Fort Bellefontaine	.....	92.6	80	[illegible]
Chain of Rocks, Missouri shore	76.9	97	84.6	[illegible]
Chain of Rocks, Illinois shore	76.9	97	77	[illegible]
Chain of Rocks intake	76.9	90	77	[illegible]
Bissells Point reservoir	86.4	94.04	93.8	[illegible]
Tap in old city hall, St. Louis	85.7	97	80	[illegible]

Discussing the percentage of the removal of bacteria per cubic centimeter at various sampling points in the St. Louis water-supply system, the witness gave the evidence set forth in Table 8. (277–279.)

TABLE 8.—*Percentage of removal of bacteria per cubic centimeter at various sampling points in the St. Louis water-supply system, September to November, 1901, the number in Mississippi River being designated as 100 per cent.*

Sampling point.	September.	October.	November.	Average.
Chain of Rocks reservoir	48.43	85.6	81.3	[illegible]
Bissells Point	86.05	90	93.5	[illegible]
Tap in old city hall	88.83	95.9	93.2	[illegible]
Tap on Garfield avenue	.....	98	92.7	[illegible]

In discussing further the number of bacteria found at various sampling points in the river, the witness called attention to the fact that the average number of bacteria in Mississippi River above Grafton, as shown by the investigations during the third period, was 717 and 2,290 during October and November, respectively, while in Illinois River above Grafton there were 1,780 and 3,050 during the same months, showing that the water of the Illinois contains the larger number. (279.)

Doctor Ravold then considered the results of the investigations of the bacterial flora and testified concerning the physical and cultural characteristics of the various bacteria isolated during the entire investigation. The characteristics of the following organisms are set forth in volume 1 of the record, pages 280–307, inclusive:

Bacteria discussed by Dr. A. N. Ravold.

Bacillus albus.
B. antenniformis.
B. aquatilis sulcatus I.
B. aquatilis sulcatus III.
B. aquatilis sulcatus V.
B. arborescens, chromogenic, orange.
B. aurescens.
B. aureus.
B. brunneus.
B. candicans.
B. cloacæ.
B. coli communis.
B. delicatulus.
B. desidiosus.
B. fluorescens incognitis.
B. fluorescens liquefaciens.
B. fluorescens tenuis.
B. fluorescens termo.
B. fulvus.
B. helvolus.
B. hyalinus.
B. iridescens.
B. lactiviscosus.
B. lactis erythrogenes.
B. liquefaciens.
B. liquidus.
B. megaterium.
B. mesentericus vulgatus.
B. nubilis.
B. ocraceus.
B. plicatus.
B. proteus mirabilis.
B. proteus zenkeri.
B. pyocyaneus.
B. rubefaciens, chromogenic, red.
B. stellatus.
B. subflavus.
B. subtilis.
B. subtilis cereus.
B. superficialis.
B. ubiquitus.
B. ureæ.
B. viridis.
Micrococcus cremoides.
M. flavus liquefaciens.
Sarcina alba.
S. lutea.

The witness gave extended definitions of bacteriological terms and a somewhat minute description of general methods of bacteriological procedure. (307–312.)

He then testified concerning microscopic organisms (algæ, etc.), describing the Sedgwick-Rafter method of procedure, and stated that two series of examinations had been made according to this method in connection with the investigations carried on by the city of St. Louis. He further stated that the object of this work was to discover the micro-organisms connected with sewage pollution, and also to attempt to trace the forms found in Lake Michigan water which are distinctive from those existing in Illinois, Mississippi, and Missouri rivers. Two sets of investigations were made—one by George A. Johnson, at the St. Louis laboratory, and one by George C. Whipple, of Brooklyn, N. Y. The long statement which Doctor Ravold then made concerning the number and genera of the organisms found in the water at chosen points is reproduced in condensed form in Table 9. (312–351.)

TABLE 9.—*Number of micro-organisms found in water at designated points.*

Family and genus.	Lake Michigan.					Drainage canal at Bear Trap dam.				
	4-mile crib.	Carter Harrison crib.	10 miles out.	Lake View crib.	2-mile crib.		June.			
	July 23.	July 30.	August 9.	September 7.	September 15.	May 27	3.	10.	17.	25.
Diatomaceæ:										
Asterionella	100	42	10	84	100	71	73	18	120	40
Cyclotella	19	12		4	16	8	2	1		
Cymbella									14	20
Diatoma	33	65	3	31	14	32	22	4	23	
Fragilaria	6		12				6			
Himantidium						2	4			1
Meridion									6	10
Navicula	11	4	14			4	6	1		
Nitzschia	60	93	86	47	62	23	7		1	14
Stephanodiscus								1	1	
Synedra	680	400	290	100	200	313	116	101	180	96
Tabellaria	30	12	26			55	16	5	16	3
Cyanophyceæ:										
Anabæna										2
Chroococcus	3			6					4	
Cœlosphærium										1
Lyngbya									1	
Oscillaria	30	20			15	15	22	38	4	
Chlorophyceæ:										
Arthrodesmus							2	1		4
Closterium	1	1		1		5				1
Eudorina							1			
Hydrodictyon						12	19			6
Pandorina									3	
Pediastrum	6	9	2	12	9				2	2
Protococcus						2	4		1	
Raphidium	4	16		4		17	7	2		
Scenedesmus	10	4	4	3						5
Spirogyra	1			4	1				4	
Ulothrix	22	10	6	14	6	15	11	16	10	
Schizomycetes:										
Beggiatoa						2		4		
Crenothrix	6	3		12	1	6		3		2
Leptothrix								6		
Protozoa:										
Amœba	2		6		1	23				
Cryptomonas	2		1							
Dinobryon	25	31	14		6		2			
Glenodinium	15	6	8	2	4					
Monas	6	15	9	12	19	32	19	21	6	47
Paramæcium						13		14	12	38
Peridinium	10	3								
Phacus								2		2
Protomonas							8	12	2	
Synura	2	6	4		1	19	6	3		1
Trachelomonas							8			
Vorticella	1	2	1			7	4	4		6
Rotifera:										
Anuræa	4	1	3	1			2			
Polyarthra		1	2							1
Rotifer	2	4	1	2	1			2		2
Crustacea:										
Bosmina						1		1		
Daphnia		1	1			1			1	
Miscellaneous	25	13	14	17	16	3	27	10	1	14
Total organisms	1,117	774	517	256	472	681	394	270	412	318
Total genera	31	26	23	19	18	25	25	24	21	25

TABLE 9.—*Number of micro-organisms found in water at designated points*—Continued.

Family and genus.	Drainage canal at Bear Trap dam.					Desplaines River at Joliet.					
	July.			August.		May 17.	June.				July 11.
	11.	20.	30.	10.	18.		3.	10.	17.	25.	
Diatomaceæ:											
Asterionella	10	6	128	130	39	34	82	96	38	138	80
Cyclotella	4		16	3		3	6		2	4	1
Diatoma	32	10		16	9	17	29		2	6	6
Himantidium			6			10	8				2
Meridion	6			7							
Navicula		6			14	5	5	12			19
Nitzschia	6	28	4		12	40	12	34	20	49	60
Synedra	30	40	88	300	220	153	196	200	90	290	240
Tabellaria	10	14		6	4	6	42	12		14	4
Cyanophyceæ:											
Chroococcus	6				2						
Cœlosphærium	4	2									
Endoriana	3										
Lyngbya	2		2		2	3	3				1
Oscillaria	10	6			6	58	60	10	19	61	75
Chlorophyceæ:											
Arthrodesmus		2		1							
Closterium							2		1		
Desmidium							1	2		4	
Dictyosphærium	1	1									
Eudorina	1				1				1	2	
Hydrodictyon			4						1		
Pandorina										1	
Pediastrum		6					2	5		7	1
Protococcus	1							4		5	
Raphidium	2			2				2	1		
Scenedesmus							2	6		16	
Spirogyra						4				2	
Ulothrix	8	2							20	10	6
Schizomycetes:											
Beggiatoa	10	8	3								
Crenothrix		12				3			1		
Protozoa:											
Chloromonas	1										
Monas	6	2		4	6	2	27	10		12	2
Paramæcium	10			31	4		3	1		4	2
Protomonas	8			6		7	2		6		2
Synura										2	3
Vorticella	2			1	2	4	3				1
Rotifera:											
Rotifer	3		2		2	3	1			2	1
Crustacea:											
Daphnia			1								1
Miscellaneous	6	2	12	7		6	22	14	40	15	33
Total organisms	182	147	284	514	323	358	508	408	242	644	542
Total genera	26	16	16	13	14	18	21	15	15	22	21

TABLE 9.—*Number of micro-organisms found in water at designated points*—Continued.

Family and genus.	Illinois River above Peoria.						Illinois River above Grafton.					
	May 27.	June.				July 11.	May 28.	June.				July 11.
		3.	10.	18.	25.			3.	10.	18.	25.	
Diatomaceæ:												
Asterionella	41	61	186	21	94	120	18	43	7	8	30	.....
Cyclotella	.....	8	.....	.....	16	4	1	.....	.....	3	2	.....
Diatoma	12	38	6	31	.....	4	7	4	2	.....	.....	2
Himantidium	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....
Melosira	.....	.....	.....	.....	.....	.....	.....	2	.....	.....	.....	.....
Navicula	.....	9	.....	.....	12	.....	2	.....	.....	.....	.....	2
Nitzschia	23	6	27	31	40	14	4	14	12	3	6	6
Pleurosigma	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	1
Stephanodiscus	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....
Synedra	71	100	22	98	209	153	46	280	140	22	90	170
Tabellaria	.....	12	.....	.....	.....	12	.....	.....	.....	.....	.....	.....
Cyanophyceæ:												
Lyngbya	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....
Oscillaria	5	.....	.....	16	64	50	1	28	20	4	.....	.....
Chlorophyceæ:												
Arthrodesmus	.....	.....	1	.....	1	.....	.....	.....	.....	3	.....	6
Closterium	1	2	1	2	.....	.....	.....	.....	.....	1	.....	1
Conferva	.....	.....	6	.....	.....	.....	.....	.....	.....	.....	.....	.....
Eudorina	.....	.....	.....	.....	.....	.....	.....	2	.....	.....	.....	.....
Hydrodictyon	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....
Pandorina	.....	.....	1	.....	.....	1	.....	.....	.....	.....	.....	.....
Pediastrum	19	29	12	6	.....	.....	4	8	.....	4	.....	.....
Protococcus	4	6	.....	5	10	6	.....	4	19	.....	6	7
Scenedesmus	14	9	18	6	5	5	4	24	.....	.....	8	10
Spirogyra	5	12	12	12	.....	.....	2	.....	.....	.....	3	3
Ulothrix	.....	.....	6	.....	30	40	.....	11	.....	.....	6	9
Zygnema	.....	.....	.....	2	.....	.....	.....	.....	.....	.....	.....	.....
Schizomycetes:												
Crenothrix	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....
Protozoa:												
Cryptomonas	.....	.....	.....	.....	.....	.....	2	.....	.....	.....	1	.....
Monas	22	12	4	.....	.....	3	8	12	6	.....	1	2
Paramæcium	.....	.....	2	2	.....	1	.....	1	1	.....	.....	1
Peridinium	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....
Protomonas	9	6	.....	2	.....	.....	.....	.....	.....	.....	.....	.....
Synura	3	.....	2	.....	.....	.....	3	2	.....	4	.....	4
Vorticella	.....	3	.....	2	5	.....	1	.....	.....	2	.....	.....
Rotifera:												
Anuræa	4	1	2	.....	.....	.....	.....	.....	.....	.....	.....	.....
Polyarthra	4	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Rotifer	.....	.....	1	.....	.....	1	.....	.....	.....	2	.....	.....
Crustacea:												
Cyclops	2	2	.....	.....	2	2	.....	.....	.....	.....	.....	.....
Daphnia	4	1	.....	.....	1	2	.....	.....	.....	.....	.....	.....
Miscellaneous	8	12	6	2	43	4	5	.....	.....	.....	.....	4
Total organisms	251	329	315	238	533	422	113	436	207	56	153	228
Total genera	19	19	18	16	17	17	20	15	8	11	10	15

TABLE 9.—*Number of micro-organisms found in water at designated points*—Continued.

Family and genus.	Mississippi River above Grafton.			Mississippi River above Alton.			Mississippi River at Hartford.			Mississippi River at intake tower.		
	May 28.	June 3.	July 11.	May 28.	June 3.	July 11.	May 29.	June 3.	July 11.	May 28.	June 3.	July 11.
Diatomaceæ:												
Asterionella	4	39	12	12	4	60	9	14	4	21	4	16
Cyclotella		4		4			4	1			2	2
Cymbella			2	2			3		2		1	
Diatoma	3	12		8	4	4	6		5			2
Himantidium							3		2			2
Meridion	4			6			2			6		8
Navicula	6			8	2	2	5		6		14	11
Nitzschia	9	60	12	10	5	15	19	30	12	32	24	16
Synedra	30	49	239	41	220	96	50	60	22	40	12	39
Tabellaria	7	2	6	9		6	12	4	4	8	6	12
Cyanophyceæ:												
Cœlosphærium							4	4	5			2
Lyngbya				2			6					
Oscillaria	2	14	2	2	19		4	10	10	20	16	22
Chlorophyceæ:												
Arthrodesmus				4		1			2	1		1
Closterium			1	2			1		1	3		2
Desmidium	1					2	2	2	3	3	3	
Dictyosphærium							6	2				
Hydrodictyon	17			4			1					4
Pediastrum		17		9	38	11	12	6	4	16	9	3
Protococcus			5	3	4		2		5	5		
Scenedesmus	8	16		4	16	12	6	12	19	26	8	14
Spirogyra				1	5		4		8			1
Ulothrix	12	22		4	29				10	4		8
Protozoa:												
Cryptomonas	1			3			3	4			2	
Glenodinium			1									
Monas	3	10	5	12	8	3	10	12	8	6	12	9
Paramæcium		1		1		1			2	1		1
Synura	5	2	2		3	3	9	3	3	3		
Vorticella				1					2			
Rotifera:												
Anurræa	1					1						
Rotifer					1				1	2		
Miscellaneous	6	12	2	5	6	2	7	11	2	3	1	2
Total organisms	119	260	289	152	364	219	190	175	142	200	114	177
Total genera	17	14	12	24	14	15	25	15	24	18	14	22

Witness then took up a part of the bacteriological data afforded by the investigations of the year 1900 and assembled it in weekly averages of the daily determinations made. (353–376.) A chart (Complainant's Exhibit No. 1) was presented, showing such data for:

Illinois river above Grafton.
Mississippi River above Grafton.
Mississippi River above Alton.
Mississippi River opposite Hartford.
Missouri River at Fort Bellefontaine.
Chain of Rocks near Missouri shore.
Chain of Rocks near Illinois shore.
Chain of Rocks at intake tower.

The information in this chart is all included in Table 4.

The witness then endeavored to show that the bacteriological data give positive evidence of the commingling of the waters of Illinois and Mississippi rivers at the St. Louis water intake at Chain of Rocks. His

observations were based on the fact, shown by a comparison of numbers of bacteria and river gage heights, observations being taken coincidently, that whenever there is a rise in either of the three streams—Illinois, Mississippi, and Missouri rivers—there is a coincident rise in the number of bacteria, and it appears that the greater the rise in water level the greater the proportionate number of bacteria. This was explained by stating that a rise in either of these streams is caused by melting snows or ice or by great precipitation, both of which result in the washing into the rivers of large amounts of filth and earth, which teem with bacteria. The witness then cited a case which appeared in the examination series beginning January 23 and ending October 9, 1900, as follows:

Illinois River was high from February 12 to 20, 1900 (dates approximate). At that time the Mississippi was low and covered with ice, as was also the Missouri. A thaw occurred in the whole Illinois River Valley, with resulting flood. The bacteriological examination shows that the waters of Illinois River contain enormous numbers of bacteria, while those of the Mississippi above the mouth of the Illinois and of the Missouri above its mouth contain a comparatively small amount. During the two weeks beginning February 13 and 20, respectively, the average number of bacteria per cubic centimeter in Illinois River at Grafton was 257,600 and 221,800, while in the Mississippi above Grafton during the same period the number was 161,000 and 105,500, and at Fort Bellefontaine, on Missouri River, the number was 52,500 and 69,500. As a result of the intermingling of these waters, the number of bacteria in the water at the Chain of Rocks intake was 133,500 and 112,000. This, in the opinion of the witness, clearly proved that Illinois River water enters the intake. Chart marked Complainant's Exhibit No. 2 was presented to support this contention. The witness called attention to the fact that during the week of January 23 the bacteria in Illinois River numbered 240,000, in Missouri River 155,000, and at the intake 150,000, the intake water corresponding very closely with the Missouri water. During the week of January 30 the number of bacteria in Mississippi River on the Illinois shore was 150,000, on the Missouri shore 75,000, and at the intake 130,000, these figures being taken within the cross section defined by the Chain of Rocks intake; and the contention was made that the figures indicate that the water at the intake was during that week comprised more largely of Mississippi River water than of Missouri River water. (376–381.)

Several charts were then introduced, and were designated Complainant's Exhibits Nos. 3 to 9, inclusive (382–404), showing weekly averages of the daily quantitative determinations of the number of bacteria per cubic centimeter in water taken from Illinois River dur-

ing 1900, together with the stages of the river during the same periods, at the following points:

Mississippi River above Grafton.
Mississippi River at Alton.
Mississippi River at Hartford.
Missouri River at Fort Bellefontaine.
Mississippi River at Chain of Rocks near Missouri shore.
Mississippi River at Chain of Rocks near Illinois shore.
Mississippi River at Chain of Rocks, intake tower.

These charts were apparently introduced for the purpose of showing the relationship between the rise and fall of the stream and the number of bacteria per cubic centimeter found in the water, and from the evidence presented by them the opinion of the witness was that coincident with a rise in the river there is always an increase in the number of bacteria, while, on the other hand, a decrease in the number of bacteria coincides with a fall in the river gage height. It was further observed that during steady periods in the stream there is a constant and steady decrease in the number of bacteria.

Two charts were then introduced, ultimately marked Complainant's Exhibits Nos. 11 and 12, for the purpose of showing the effect of the Chicago drainage canal on the water in the river at Peoria. These charts, which are not reproduced, contain the results of the bacteriological determinations made during the period from September to November, 1901, assembled in diagrammatic form for the following sampling points:

Chicago drainage canal at Bear Trap dam, Lockport.
Desplaines River at Ruby street, Joliet.
Desplaines River at Brandon's bridge, Joliet.
Illinois River 3 miles above Peoria.

From an examination of these diagrams the witness noted an enormous fluctuation in the bacterial content at the Bear Trap dam, the number varying from 25,000 to 7,200,000 per cubic centimeter. The variations are relatively as great and are practically synchronous at the three lower sampling points. The record of river stages at Peoria indicates that the river was steady during this period to an extraordinary degree; in fact, the greatest change in the river levels during any one period of twenty-four hours was 0.2 foot, and the entire variation from beginning to end of the period was 0.6 foot. It was claimed by Doctor Ravold that this is unimpeachable testimony concerning the effect of the Chicago drainage canal on the river at Peoria. The great diversity in the number of bacteria in the water, along with the extraordinary steadiness in the river stage, taken in conjunction with the observed fact that in Desplaines River above Bear Trap dam comparatively small numbers of bacteria were found, could, in the

opinion of the witness, be accounted for in no other way than by the entrance of sewage from the Chicago drainage canal. (449–460.)

The witness then introduced another chart, showing the results of daily quantitative determinations of bacteria and the daily stages in Illinois River from October 1 to November 27, 1901, at Grafton, 163 miles below Peoria by river. He stated that the greatest number of bacteria per cubic centimeter occurred November 17; that while there was a slight rise in the river on that date it was not as high as it had been from October 21 to 30, when the number of bacteria had been comparatively low. No further attempt was made by the witness to discuss these results, although it is clear from a reading of his statements that he inferred that such results lead to the belief that the great mass of bacteria were due to artificial contamination rather than to any natural causes, and therefore were presumably contributed by the drainage canal.

The witness then outlined the results of a series of experiments made to determine the longevity of *Bacillus typhosus* in sterilized distilled water and in sterilized water from chosen points in Mississippi and Illinois rivers. These results are set forth in condensed form in Table 10. (468–470.)

TABLE 10.—*Longevity, in days, of Bacillus typhosus in sterilized water under various conditions.*

Source of water.	Cultures in darkness at 10° C.			Cultures in darkness at 20° C.			Cultures in open window facing east, in summer.		
	A.	B.	C.	A.	B.	C.	A.	B.	C.
Distilled	51	25	22	22	54	30	22	25	4
Mississippi River above Grafton	59	.....	40	.....	37	.....	.....	45	6
Drainage canal at Lockport	45	.....	22	54	54	.....	40	31	2
Missouri River at Fort Bellefontaine	59	57	57	.....	.....	57	.....	.....	.....
Mississippi River at Chain of Rocks	59	59	34	54	55	54	.....	46	4

A second series of tests on the longevity of *Bacillus typhosus*, made to determine the length of time in which the bacillus persists in live water, was then described. Samples of water were collected at various times from Chicago River, the drainage canal at Lockport, Illinois River at Peoria, and Mississippi River at the Chain of Rocks intake. Then 200 c. c. of each of these samples were poured into sterilized Erlemeyer flasks and carefully stoppered. Some flasks were exposed to sunlight by placing them upon a shelf in a window facing the south, where the direct rays of the sun impinged on them from 10.45 a. m. to 2.15 p. m., the total average time of exposure daily being about three hours. Others were kept in cold storage. The results were as shown in Table 11. (470–477.)

TABLE 11.—*Longevity, in days, of Bacillus typhosus in water from various sources.*

Sampling point.	Length of life in—	
	Sunlight.	Refrigerator.
Chicago River at Adams street	4	5.5
Drainage canal at Western avenue, Chicago	6	7.5
Drainage canal at Lockport	4.75	10.66
Drainage canal above controlling works, Lockport	.....	9
Drainage canal at Jackson street, Joliet	9	13
Illinois River above Peoria	7.66	11.5
Illinois River at Pekin	7	15
Laboratory tap, St. Louis	7	12
Chicago River at Adams street (sterilized water)	16	.....
Drainage canal at Lockport (sterilized water)	.....	23

The witness then discussed the results of other tests during June, July, and August, 1900. Sterilized distilled water at 10° C., culture A thirty-three days, B thirty-five days, C thirty-one days; sterilized Mississippi water, Grafton, culture A fifty-five days, B fifty-two days, C fifty-seven days; sterilized Missouri water, Fort Bellefontaine, culture A fifty-five days, B sixty-two days, C sixty-five days; sterilized Illinois River water, Lockport, culture A forty-four days, B fifty-eight days, C thirty-one days; sterilized Mississippi water, intake, culture A fifty-one days, B fifty-four days, C fifty-two days. (477–478.)

Testifying further, the witness stated that it was impossible to obtain in laboratory experiments the conditions which prevail in a running stream; but inasmuch as the laboratory conditions are more unfavorable to the longevity of typhoid bacilli than the stream conditions the results of laboratory experiments are conservative. He said that it had never been determined how long bacteria survive in a running stream. (478–480.)

In reply to questions concerning the population tributary to the Illinois River system, and the Chicago drainage canal, the amount of sewage derived from the population and the effect thereof on the streams involved, Doctor Ravold testified as follows:

The sewage of upward of 2,000,000 people enters the Chicago drainage canal above the controlling works at Lockport. Determinations made by the witness and confirmed by the work of other investigators reveal the fact that from 3 to 6 ounces, dry weight, of fecal matter and 40 ounces of urine are voided each day by the normal human being. A calculation based on 3 ounces of solid matter and 40 ounces of liquid per capita, and 2,000,000 as the population tributary to the Chicago drainage canal, would give a total excretion of 187½ tons of fecal matter and 670,000 gallons of urine per day. It is commonly assumed that the amount of sewage in a city is fairly represented by the amount of water consumed. The water consumption in Chicago being placed at 150 gallons per capita per day, the total daily sewage discharge would be 360,000,000 [300,000,000?] gallons. (767-769.)

Doctor Ravold then calculated the percentage of sewage to water in the Chicago drainage canal at the controlling works. The maximum discharge over the controlling dam being 300,000 cubic feet per minute, the proportion of sewage to pure lake water would be 1 to 9. The effect of all this contamination was to render the water at the controlling works extremely foul, and the results of the bacteriological examinations which he had presented were sufficient to substantiate this statement. One of the observers employed by the city of St. Louis had seen 500 dead fish pass over the controlling dam in a period of ten minutes. (769-770.)

With reference to the city of Peoria, the witness stated that a calculation based on a population of 56,100, as given by the census of 1900, the minimum flow of Illinois River past Peoria of 1,200 cubic feet per second, and a sewage outfall at Peoria proportional to that of Chicago, namely, 150 gallons per capita per day, would give the proportion of sewage to water 1 to 92 at the low-river stage. The witness stated that if the 300,000 cubic feet per second added by the Chicago drainage canal were unpolluted lake water the dilution of sewage at Peoria would be 1 to 413, which, in his opinion, would reduce to a minimum the danger from Peoria pollution to the places below, such as Grafton. (772-773.)

Doctor Ravold then gave facts concerning the population in the drainage basin of Illinois River and the sanitary district of Chicago giving credit for the data to Lyman E. Cooley and Jacob A. Harman. The information is summarized in Table 12. (774-776.)

TABLE 12.—*Population of Illinois River drainage basin.*

River basin.	Flow.	Population.		
		Urban.	Rural.	Total.
	Second-feet.			
Desplaines River	13.21	20,354	45,247	75,6
Dupage River	32.77	5,344	10,890	16,2
Kankakee River	509.24	26,697	140,441	170,1
Fox River	329.95	72,763	89,889	162,6
Vermilion River	4.00	17,543	43,257	60,8
Mackinaw River	.....	5,247	30,106	35,3
Spoon River	87.76	19,619	56,423	76,0
Sangamon River	372.30	103,720	177,638	281,3
Crooked Creek	.....	12,739	44,289	57,0
Macoupin Creek	.....	9,155	32,296	41,4
McKees Creek	.....	.....	8,823	8,8
Illinois River a	.....	135,139	184,877	330,0
Sanitary district of Chicago	.....	1,800,000	.....	1,800,0

a Not including drainage canal.

Taking up the sources of pollution along Mississippi River below Illinois River, the witness stated that Alton had a population of 15,000. The sewage from this city is discharged into the Mississippi by five main outlets, three of which empty into the river behind dikes, which effectually check that portion of the sewage from becoming mixed at once with the waters of the river. (776.)

He then summarized the bacteriological evidence with reference to sampling stations maintained above Alton and at Hartford, a few miles below Alton, the results of which are given in Table 13. (778-778.)

TABLE 13.—*Monthly averages of quantitative bacteriological determinations of Mississippi River water 1 mile above Alton and opposite Hartford, and percentage of samples in which Bacillus coli communis was found.*

Month.	Alton.		Hartford.	
	Bacteria per cubic centimeter.	Per cent of B. coli communis.	Bacteria per cubic centimeter.	Per cent of B.coli communis.
1900.				
January	118,800	14	90,600	17
February	192,500	17	190,600	50
March	192,300	51	208,300	52
April	29,400	39	29,700	41
May	10,300	54	12,800	86
June	8,200	60	5,800	61
July	7,700	52	61,000	55
August	2,400	88	2,100	89
September	2,600	99	2,800	93
October	2,100	100	2,400	100
1901.				
October	1,137	100	2,141	86.4
November	1,566	77	3.000	56

Taking up the consideration of this evidence, the witness stated that if it is assumed that the whole sewage of Alton becomes mixed with the water of the Mississippi at once and is carried directly toward Hartford with a minimum flow of 25,000 cubic feet per second in the river, it will be seen that the Alton sewage, representing 15,000 people, is diluted over 70,000 times; in fact, the results in Table 13 above indicate that the sewage is so largely disposed of by dilution that the bacteriological results at Alton and Hartford show no difference. From the evidence thus presented, the witness asserted that it was his expert opinion that "the sewage of the city of Alton has no effect on the sanitary condition of the Mississippi River water at Hartford." (778–779.)

Doctor Ravold then proceeded to a discussion of the work performed by him with reference to *Bacillus prodigiosus* and its longevity when placed in the waters of Mississippi and Illinois rivers. Inasmuch as the testimony created considerable comment at the time and was brought out by the witness as a strategic move of great importance to the plaintiff's case, it will be given nearly in full. (779–787.)

The *Bacillus prodigiosus* is a micro-organism discovered by Ehrenberg. It is a trifle larger than the typhoid bacillus and is nonspore forming and nonpathogenic. The name was derived from the fact that in European countries the host in the chalice of Catholic churches has a red growth upon it which in early times was declared to be the blood of Christ. This red growth was investigated and found to be

in one case a micro-organism which produces within its cell a red pigment. This is the legend connected with the name, and it was called therefore *B. prodigiosus*. It has been very rarely found in the waters of America and apparently is not a germ which is domestic to this country, although it is said that in Europe and in Egypt it is found abundantly in surface waters. It grows very freely on the ordinary culture media, and its behavior and appearance are so characteristic that it is easily identified.

In the investigation made by the witness, beginning in August, 1899, and extending to August, 1900, every sample of water that was received was examined for distinctive bacilli, but *B. prodigiosus* was never found. Throughout the examinations it never appeared in over 10,000 samples of water from Lake Michigan, the drainage canal, Mississippi and Illinois rivers, except when it was placed there by the St. Louis investigators. It was therefore concluded that *B. prodigiosus* was not a normal inhabitant of the streams under investigation and that it was rarely, if ever, present.

In August, 1900, the witness prepared a 40-gallon barrel full of a broth culture of *B. prodigiosus*. The barrel was first sterilized with steam heat and was then filled with boiling hot water and allowed to stand until cool, but while the water was boiling hot 1 pound of sterilized Liebig's beef extract was mixed into it. After two or three days when the water was sufficiently cool, a large number of *B. prodigiosus* in a broth culture were placed in it. This particular culture of *B. prodigiosus* came from Europe and was given to the witness by Dr. Ludwig Bremer several years previous. The barrel culture was allowed to develop until it was found that each cubic centimeter of the broth contained over 1,000,000,000 bacilli. August 31, 1900, this barrel of *prodigiosus* broth was emptied into the Mississippi just below the mouth of Illinois River. September 3, four days later, the organism was found in a sample collected in the channel of the river above Alton, but at no other place. September 20 the experiment was repeated. A barrel containing 40 gallons of the same culture was emptied at the same point, and September 23 the organism was found in a sample collected near the Illinois shore of the Mississippi at Chain of Rocks. October 18 the bacterium was again found in a sample collected from the laboratory tap at the old city hall, St. Louis, and October 24 in a sample collected near the Illinois shore of the Mississippi at Chain of Rocks.

Preparations were then made for an extensive experiment which it was believed would be conclusive. The object was to empty into the Chicago drainage canal a large quantity of *Bacillus prodigiosus* and to identify it, if possible, along Illinois River and even to the St. Louis intake. The witness made the following preliminary statement: "I must say that in the first place I needed a courageous man to do this

thing—a very powerful man—and I didn't know where to look for him except in a brother of mine whom I brought up from Arizona; he knows a thing or two about taking care of himself and is physically a powerful man." November 6, 1901, "in spite of the active vigilance of the police," E. J. Ravold successfully emptied into the drainage canal at Lemont, 8 miles above the Bear Trap dam, 107 barrels of *prodigiosus* broth, which contained 40 gallons each. There were over 1,000,000,000 bacilli per cubic centimeter in each of these barrels.

All the laboratories along the river were notified and samples were collected every hour of the day and night at the Bear Trap dam, in the drainage canal; at Joliet, Peoria, and Grafton on Illinois River; and at the intake of the St. Louis waterworks at Chain of Rocks. The bacillus was not found by Dr. W. C. G. Kirchner, stationed at Joliet. It was found at the St. Louis laboratory in a sample collected by Mr. Werner at the intake tower, Chain of Rocks, at 8.45 a. m., December 4, and again on the 5th, in the sample collected at 9 a. m. It was found December 6 in a sample collected by Mr. Homer from Illinois River above Grafton at 8 a. m., and again in a sample taken from the same point at midnight, December 7. (779–784.)

Doctor Ravold then described experiments made to determine the longevity of *Bacillus prodigiosus*, the results of which are set forth in Table 4. (785.)

TABLE 14.—*Longevity of Bacillus prodigiosus in water under different conditions.*

Source of water.	Sterilized.	Place kept.	Duration of sunlight.	Temperature.	Longevity.
			Hours.	*°C.*	*Days.*
Laboratory tap[a]	Yes	Open air	9.5		2
Drainage canal above Lockport	No	Window	3		10
Desplaines River at Joliet	No	do	3		7
Chicago River at Adams street	Yes	do	3		11
Drainage canal at Lockport	No	Refrigerator	Dark.	16	32
Desplaines River at Joliet	No	do	Dark.	16	†41
Drainage canal at Western avenue, Chicago	No	do	Dark.	16	31
Illinois River at Pekin bridge	No	do	Dark.	16	†53

[a] Suspended on cord, 8 feet from south wall of laboratory building.

Comparing the above results with similar tests made on the bacillus of typhoid, which are outlined in previous pages, Doctor Ravold concluded as follows:

With these micro-organisms side by side, comparative estimates were made of the longevity of *Bacillus typhosus* and *B. prodigiosus* in separate samples of water, collected at the same time and place, and kept under the same conditions as to temperature, sunlight, and darkness. *B. prodigiosus* in sunlight, in living waters, that is, non-sterilized waters, lived from two to ten days; *B. typhosus* in sunlight and in living waters lived from twenty-four hours to ten days. *B. prodigiosus* lived in the dark, in living waters, from thirty to fifty days and was still alive when the experiments ceased; *B. typhosus*

under like conditions lived from twenty-four hours to twenty-one days, showing that *B. prodigiosus* is an organism which closely resembles *B. typhosus* in its power to resist unfavorable surroundings.

As a result of these experiments the witness declared it to be highly probable that a typhoid bacillus can be carried in its virulent condition from the Chicago sewers, by way of the drainage canal and Illinois River, into the St. Louis water intake, especially during high-water conditions. (788)

Continuing, the witness testified that it was impossible to determine the absolute longevity of the typhoid bacillus in running water, because the conditions which prevail in a running stream can not be reproduced in laboratory experiments. In stagnant waters, such as are kept under observation in laboratory experiments, the water bacilli destroy the life of the typhoid bacilli. If typhoid bacilli are placed in foul water, such as that taken from the Chicago drainage canal, the water bacilli increase enormously, but the typhoid bacilli do not increase. The destructive action of the water bacillus on organic matter, both solid and liquid, in water results in the production of poisons which act deleteriously on both the water bacillus itself and the pathogenic organisms in the water, so that in laboratory experiments bacilli die much more quickly in living water than they do in water which has been sterilized. In streams, however, the typhoid bacilli, which are motile, can move out of the influence of these poisons and thus prolong their life. (790–791)

In response to a series of questions concerning the probability of destruction of bacteria by sunlight in streams, the witness stated that the assumption that bacteria were destroyed in a few hours by this cause is unfounded, although there is no doubt that the effect of sunlight is detrimental. Practically, this effect depends on the character of the stream and especially the turbidity of the water and the depth to which it will admit the sun's rays. A turbid water will protect bacteria from the sun; in the Illinois, for example, the effect of the sun would be dissipated in a depth of less than 1 foot. It was then brought out, by leading questions of counsel, that in the opinion of the witness the bacteria are endowed with instincts of self-preservation and, being motile, can escape from adverse conditions in the water. In case the sun's rays are detrimental, they can go deeper into the water, and if they enter strata of water having a greater velocity than at the surface or at the bottom of the stream, they will be carried downstream at a faster rate, to the increased detriment of municipalities along the lower reaches of the stream which take their supply from it. (797–799)

The witness then asserted that in his opinion the bacteriological experiments indicate that bacteria discharged by the drainage canal, especially in high-river stages, are carried into Mississippi River by

way of Illinois River and enter the intake of the St. Louis waterworks. Bacteriologically, the water of the Mississippi at the St. Louis intake is impure and unfit for human consumption. (799–803)

The witness then sought to justify his conclusions taken from his experimental work on longevity of the typhoid bacillus as follows:

Bacillus typhosus will survive in sterilized distilled water, or water containing no food supply, "a great number of days." In sterilized river water containing no water bacteria, but retaining the food supply and many of the toxins produced by bacterial life, they will live "a great number of days," experiments having shown that at the end of sixty-five days they were still alive. In unsterilized river waters, or "living waters," in flasks sown with typhoid the water bacteria increase enormously either in the sunshine or in the dark refrigerator at 16° C., up to a point at which they have apparently exceeded the food supply and—what is more important—have produced toxins which injure or actually destroy the other bacteria. Nevertheless, in the experiments of the witness the typhoid bacillus lived under these identical conditions a maximum period of twenty-one days. Several theories which have been promulgated to account for the disappearance of bacteria in living waters were then explained. First, the plankton, or the lower forms of animal and vegetable life which inhabit waters, are said to feed on bacteria. This, according to the witness, is not substantiated by any scientific proof. The second theory assumes the absorption of food supply by the associated bacteria. The witness believes this to be unimportant, because of the fact that, as experiments show, the typhoid bacillus lives for "a great number of days" in distilled water. Third, the toxins produced by the associated bacteria have a destructive action on the typhoid bacilli. Now, in streams where water is in constant motion, carrying away the toxins produced, and where the food supply is abundant and the bacteria per cubic centimeter less numerous, the typhoid bacillus can swim away from "uncomfortable surroundings." It would therefore seem that the conditions which prolong the life of the typhoid bacillus would act more favorably in a running stream than in the stagnant water of a laboratory flask. Therefore, in the opinion of the witness, conclusions based on laboratory experiments err, if at all, on the side of safety. (804–807.)

The laboratory experiments indicate that bacteria would live from four to twenty-one days in the various streams connecting the Chicago drainage canal with the Mississippi at St. Louis. If, however, the more favorable conditions in the running streams were taken into consideration, a conservative estimate of the longevity would be from fifteen to thirty days. Assuming, then, that the time consumed in traveling from Chicago to the St. Louis intake would be seventeen days, and allowing three days more for storage at St. Louis and final

distribution, the witness regarded it as highly probable that typhoid organisms would be delivered to the consumer in a condition sufficiently virulent to cause disease in a susceptible individual. (807–808.)

After discussing the various factors which cause the disappearance of bacteria in running water—namely, aeration, dilution, sunlight, sedimentation, disappearance of food supply, and production of toxins—the witness stated that sedimentation and dilution are the prime factors, and that in case a large number of pathogenic bacteria are deposited on the bottom of a stream by sedimentation they would not necessarily be killed by this process, but would be washed up again by any disturbance, such as a freshet or dredging, and would be carried downstream and probably cause disease. Under such an assumption the witness admitted that the longevity of the organisms would be a factor and that some of them would be destroyed by infusorial life. (809–813.)

The witness then considered the series of samples collected between February 8 and 20, 1900. These samples came from Illinois River at Peoria and Grafton, from Mississippi River above Grafton and at Alton and Hartford, from Missouri River at Fort Bellefontaine, and from Mississippi River at Chain of Rocks along the cross section defined by the intake tower and the Illinois and Missouri shores. The samples from Illinois River at Peoria and Grafton were almost black, the Mississippi water above Grafton was remarkably clear, while Mississippi River flowing by Alton and Hartford showed a mixture of the two waters. That from Missouri River was exceedingly clear, as was that taken from Mississippi River near the Missouri shore at Chain of Rocks, but the Mississippi water near the Illinois shore was black. At the intake tower there was a distinct mixture of the clear and the black water which represented a mean between the two streams on either side of the river. The bacteriological results confirmed unmistakably the conditions indicated by physical examination. The number of bacteria in the Illinois samples was very high; a lower number appeared in the Mississippi samples above Grafton, and the lowest in Missouri River at Fort Bellefontaine, while the samples taken from the intake tower showed a distinct mixture. The rivers were covered with ice during this period. Subsequent to this, but within the incubation period of typhoid fever, there was an enormous increase in the occurrence of the disease in St. Louis, 117 cases and 16 deaths occurring in March. In connection with this the witness recalled the fact that the Chicago drainage canal had been opened January 17, and that the samples just discussed were collected from February 8 to 20 following. There was a heavy thaw in the Illinois River basin about February 10, which did not extend to the basins of the upper Mississippi and Missouri until

some time later, and therefore the Illinois River water largely predominated in the Mississippi at St. Louis. From this the witness deduced the following conclusions: A great mass of filth had accumulated in the Chicago drainage canal previous to its opening. When the Bear Trap dam was lowered this material rushed down the valley and could be readily traced by the naked eye. At that time Illinois River was low, and the greater part of the foul mud was finally deposited on the bottom of the stream. As during the winter months the anaerobic bacteria were ineffective, the foul material remained unchanged, and when it was carried down into the Mississippi by the flood it must have been in a highly virulent condition. (835–840.)

Pages 406–449, inclusive, of the record give the testimony of the witness in regard to typhoid at St. Louis. He stated that prior to 1895 the St. Louis water intake was located at Bissells Point, about 3 miles above Market street and just above the present Merchants Bridge across Mississippi River. About 1,000 feet above this intake Harlem Creek discharges into the Mississippi. At that time probably about 10,000 people lived in its drainage area, the sewage from whom, as well as offal from a number of dairy stables, discharged into this creek. All this material during freshets was washed into the Mississippi and at times flowed directly into the Bissells Point intake. The result was an extended epidemic of typhoid fever in St. Louis, beginning in August, 1892, and continuing until February, 1893. The water commissioner placed a dam across Harlem Creek 500 yards back from Mississippi River and diverted the water downstream to a point below the intake, with the result that the epidemic was ended. Typhoid fever, however, continued to be excessive in St. Louis until 1895, when the intake was removed to its present location at Chain of Rocks, after which there appeared to be a great improvement.

The witness gave the number of cases of typhoid fever and deaths therefrom in St. Louis during each week of the period 1890 to 1900, inclusive, with the exception of 1892, 1893, and 1894. The figures appear on pages 419 to 432, inclusive, of the record. The monthly statement computed from these and other figures is reproduced in Table 1.

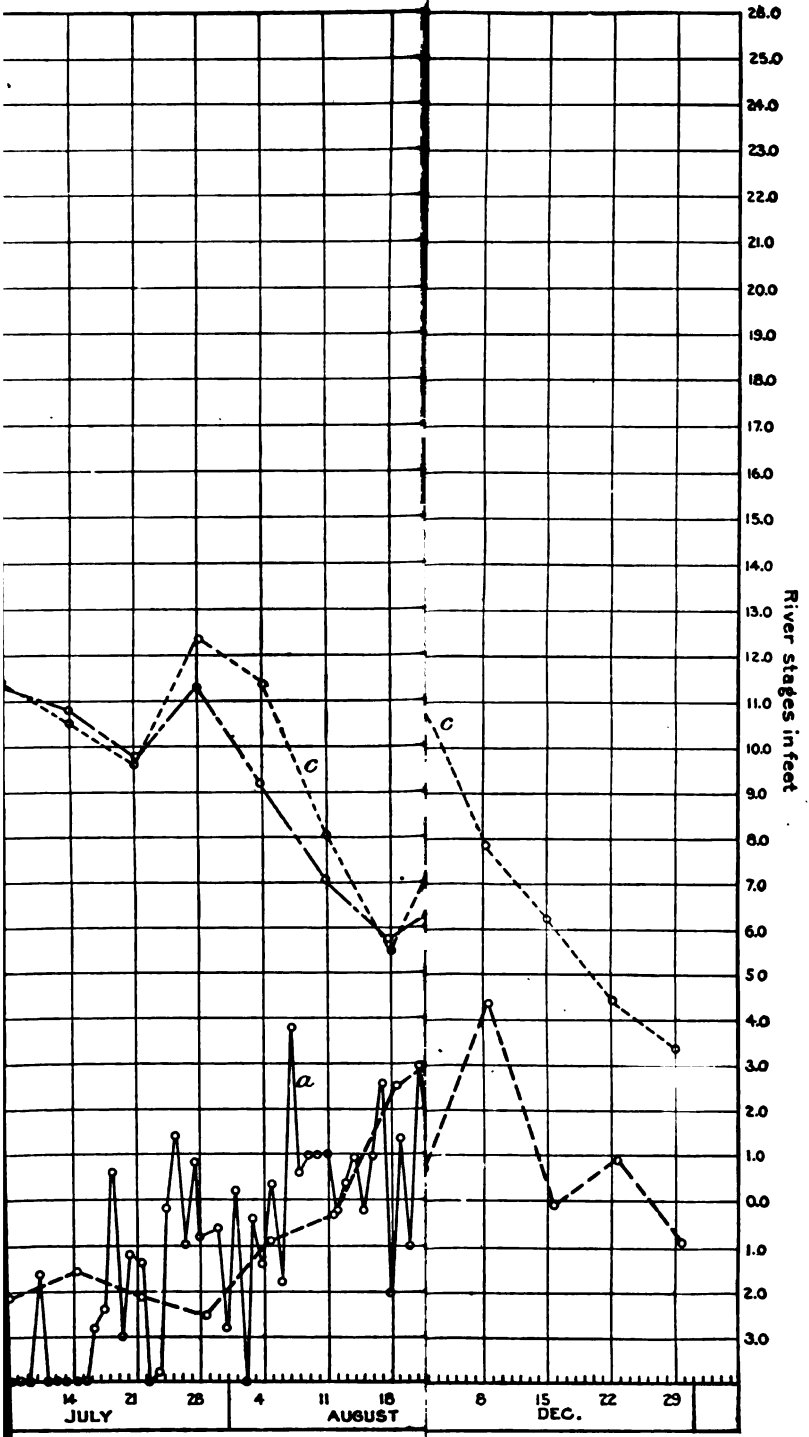
The evidence given in Table 1, together with a statement of Mississippi River gage heights at St. Louis during coincident periods, was introduced in diagrammatic form and designated Complainant's Exhibit No. 10. The diagram showed simply that as a whole low gage heights were accompanied by high typhoid morbidity in St. Louis.

A special chart, designated Exhibit No. 10a, was then introduced into evidence and is herewith produced as Pl. I. It contains curves indicating the number of cases and deaths from typhoid fever

in St. Louis during the year 1900, gage heights of Mississippi at St. Louis and of Missouri River at Hermann, Mo., duri period, and the proportion of Mississippi River water enteri St. Louis waterworks intake at Chain of Rocks, determined a ing to the relative amounts of total solids found in daily sam the water taken from Missouri River at Fort Bellefontaine an Mississippi River at Hartford and at the intake. This met determination will be discussed in connection with the testim Professors Keiser and Teichmann.

In discussing Exhibit 10a (Pl. I) the witness called attent the fact that in the early part of the year 1900 the propor Mississippi River water entering the intake increased, reachi per cent February 8, but falling rapidly to 12 per cent Februa The period of incubation of typhoid fever varies from five days to three or four weeks. March 3, or twenty-three days February 8, the date at which 100 per cent of Mississippi water entered the intake, there was an increase in the num typhoid cases, which reached a maximum March 17. The w further called attention to the fact that from January 27 to ruary 10 both Mississippi and Missouri rivers were falling, bu according to the gage height records at Peoria, Illinois Rive high. These records show that there was a steady rise from uary 17 to 29, and the inference drawn from this was that a percentage of Illinois River water was directed into the inta Chain of Rocks and produced the typhoid above noted. Mar 25, 26, 27, and 28, 100 per cent of Mississippi River water was into the intake. There was a fall to 62 per cent on March 29 rise on March 31 to 100 per cent. April 1 the proportion was 8 cent; April 2, 50 per cent; April 3, 62 per cent; April 5, 56 per April 6, 32 per cent; and April 7, 1 per cent, after which i rapidly. The proportion of Mississippi River water in the i fell during the summer, fluctuating until August 7, when it re 6 per cent. By August 31 it had risen to 50 per cent. Duri this time the number of typhoid cases in St. Louis increased the increase in the proportion of Mississippi River water a intake tower. This proportion fluctuated between 10 per cent tember 15 and 46 per cent September 22. After this there w steady rise, until a percentage of 64 was reached October 4. I again October 6 to 27 per cent, rose on the 7th to 42, fell on th to 24, and rose on the 10th to 26. From all this Doctor Ra concluded that when the volume of the river is very great the centage of typhoid is very low, and that the typhoid increases the increased percentage of Mississippi River water going into intake. (432–447.)

Doctor Ravold described in some detail the great typhoid



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demics at Plymouth, Pa., and at Lowell and Lawrence, Mass., as well as several which had taken place in Europe. (463–467, 739–752.)

He then gave a record of the deaths from typhoid fever in representative foreign and American cities, the substance of which is included in Table 15. (753–755.)

TABLE 15.—*Deaths from typhoid fever per 100,000 population in different cities, 1890–1896.*

Year.	Filtered or upland water supplies.				Polluted water supplies.			
	Rotterdam.	Munich.	Berlin.	Vienna.	Chicago.	Pittsburg.	Louisville.	St. Louis.
1890	6	8	9	9	92	.....	88	94
1891	4	7	10	6	154	100	81	39
1892	6	3	8	8	106	100	72	37
1893	5	15	9	7	45	111	84	103
1894	5	2	4	5	31	56	72	31
1895	2	3	5	6	32	77	77	19
1896	12	3	5	5	46	61	45	19

Continuing, Doctor Ravold discussed a chart which was presented in evidence, showing the incidence of typhoid fever and its results in St. Louis during the decade 1890–1900. The chart emphasizes especially the fact that from January, 1890, to September 28, 1894, during which time the water supply was taken from Bissells Point, where it was constantly contaminated by the waters of Harlem Creek, the cases of typhoid fever numbered 6,222 and the deaths 1,268. During the period from September 28, 1894, to December, 1900, when the supply was taken from the new intake at Chain of Rocks, the cases of typhoid fever numbered 2,490 and the deaths 562, indicating plainly a decrease in typhoid-fever rate of 125 per cent. This chart further showed that during the three years intervening since the opening of the Chicago drainage canal and the end of the year 1902 there had occurred 3,246 cases of typhoid fever and 588 deaths, an increase since the opening of the canal of 68 per cent.

The record for the three years previous to and the three years subsequent to the opening of the Chicago drainage canal is as follows:

TABLE 16.—*Typhoid-fever cases and deaths at St. Louis, 1897–1902.*

Year.	Cases.	Deaths.	Year.	Cases.	Deaths.
1897	433	125	1900	1,213	168
1898	426	95	1901	1,101	198
1899	948	130	1902	1,112	222

The witness endeavored to explain the increase in the number of cases occurring in 1899, previous to the opening of the Chicago drainage canal, as due to the fact that in that year the water in Mississippi River was so low that it was feared that the lowest gates in the intake tower would not admit enough water to supply the city, so that a cofferdam was built about the intake and workmen were engaged to

put a lower gate in the tower, the contention being that the unavoidable stirring up of mud which accompanied this work was responsible for the increase in the typhoid-fever rate during that year. The witness stated that in addition to this, extensive dredging was going on in Illinois River at Kampsville. (763–765.)

With reference to the comparative reliability of morbidity and mortality statistics in determining the prevalence of typhoid fever, the witness expressed a preference for the mortality data and justified his conclusions as follows:

> When we go back over the statistics—that is, of the typhoid-fever cases and deaths—take the case of Plymouth, for instance; there were 1,104 cases and 114 deaths, 10.3 per cent; in other words, 10 out of every 100 died; and my personal experience in this city, in hospitals, would make the per cent anywhere from 7 to 15, depending upon the stage of the disease in which the typhoid cases reached the hospital, while in my experience for twenty years as a practicing physician in this city, in the treatment of typhoid fever, the relation of deaths to cases would not be 1 to 15—that is, practising in the homes of the individuals sick. The reason for this is that we see the cases early and can do more for them at home, while in the hospitals the patient reaches there after he is seriously sick and the chances for treatment and recovery are not so good, so these figures on the chart, showing the relation of cases to deaths, are not comparable at all.
>
> Take any one of these years—any one you may please. We find that for 1892, for instance, we have 488 deaths and 3,624 cases recorded. There ought to be at least 5,000 cases recorded by physicians—or take the lowest there, 1898, 95 deaths, which would mean 950 cases in the town.

The witness concluded from this that physicians had not reported every case, but reported necessarily every death. (765–766.)

CROSS-EXAMINATION.

The most of the cross-examination (837–949) consisted of a review of the statements already made by the witness, and only a few of the important facts not brought out during the direct examination will be mentioned here.

The witness stated that the results of the examination of the water of Illinois River carried on during 1899 were not, in his opinion, a fair test of the conditions.

A series of questions was then put to the witness, the purpose of which was apparently to show that, sedimentation and dilution being important factors in the disappearance of bacteria from water, the conditions along Illinois River were favorable for such disappearance. The witness conceded that there must be considerable sedimentation at numerous points along the river where the channel assumed the form of a basin, or where dams were built across the channel. He denied that there was any significant amount of sedimentation in the basin at or near Joliet, but conceded that at such places as La Salle, Peoria, Henry, Copperas Creek, Lagrange, Beardstown, and Kampsville considerable sedimentation occurred. The witness confessed ignorance concerning the amount of water normally contributed by

itary streams of the Illinois basin, but admitted that nsiderable dilution. It was then admitted that there pi River and its tributaries entering above St. Louis es which discharge raw sewage into the streams, and impossible to determine whether typhoid bacilli occur- er at the St. Louis intake came from the Chicago drain- rom the sewers of the cities mentioned. He further the drainage area of Illinois River was very small com- at of the Missouri and upper Mississippi and stated that as to the dangerous quality of water from Illinois River the discovery not of organisms which actually produce rather of kindred species which are known to accompany

avold admitted that there had not been in this country ic report of a water-borne typhoid epidemic in which the ce of contamination was at a greater distance than about ut explained this by stating that when greater distances ved the difficulty of such proof became insurmountable, as there were always other towns in the drainage area which ed the field of research.

ness expressed his opinion that no running stream on which villages are situated is fit as a source of water for domestic out purification, and in this connection many instances of epidemics were cited to support his statement.

WILLIAM C. TEICHMANN.

DIRECT EXAMINATION.

William C. Teichmann, a witness called in behalf of the com- it, testified that since April, 1893, he had been city chemist of uis. He was graduated from the academic department of ngton University in 1875; in the fall of the same year entered olytechnic College of Brunswick, Germany, and there studied stry until the summer of 1879; in the fall of 1879 he entered the ity of Berlin ntinued the study of chemistry and other During d he m specialty of water analysis nann. he entered the University e Un Munich, remaining there of philosophy in chemistry try in 1885 he engaged in took up chemistry and professor of chem- In 1891 he became ining this position n the analysis of

waters, disinfectants, medicines, and articles of food under the department of health and for the city institutions, together with toxicological work for the police department. (1148–1150.)

Doctor Teichmann stated that he had charge of the chemical part of the entire investigation carried on by the complainant; that he had organized the system of collection of chemical samples and had directed as well as taken part in the chemical procedure. The chemical work was divided into several periods, which will be taken up in chronological order. (1151–1155.)

The first period commenced August 23, 1899, and closed January 22, 1900. The samples were not taken at regular intervals, but only at such times as the city harbor boat and the funds at the disposal of the witness permitted. The total number of samples collected during this period was 142, taken from the following points (641–643):

Samples of water collected from August 23, 1899, to January 22, 1900.

	Number of samples.
Mississippi River at Chain of Rocks, near intake tower of St. Louis water supply	26
Mississippi River at Chain of Rocks, near Missouri shore	3
Mississippi River at Chain of Rocks, near Illinois shore	3
St. Louis waterworks distributing well	28
Mississippi River at Madison Landing, between Chain of Rocks and mouth of Missouri River, near Missouri shore	3
Mississippi River at Madison Landing, near Illinois shore	7
Mouth of Missouri River	10
Mississippi River at points between Alton and mouth of Missouri River	13
Mississippi River at Clifton Terrace	6
Mississippi River at Elsah	5
Illinois River at points 1, 2, 3, and 5 miles above Grafton	19
Mississippi River at points 1, 2, 3, and 5 miles above mouth of Illinois River	19

For about two months from the beginning of the work the samples were collected in demijohns held in the hand under the surface of the water. After this period collecting machines were devised and the water was taken at a point from 3 to 4 feet beneath the surface. The capacity of the bottles was one-half gallon. After the sample was taken a cloth was tied over the stopper and the neck of the bottle or demijohn, and a tag was attached to the bottle with sealing wax, the seal of the city chemist's office being used. (644–645.)

The second period extended from January 23 to October 11, 1900, the number of samples collected and analyzed during that period being 3,492. The samples were taken from the following points (1182–1183):

Samples of water collected from January 23 to October 11, 1900.

	Number of samples.
Lake Michigan	11
Chicago drainage canal above Bear Trap dam at Lockport	219
Desplaines River at Joliet	219
Illinois River 3 miles above Peoria	260

	Number of samples.
Illinois River 3 miles below Pekin	1
Illinois River at Pekin Bridge	1
Illinois River at Wesley	1
Illinois River 3 miles above Grafton	265
Mississippi River 2 miles above Grafton	264
Mississippi River 1 mile above Alton	260
Mississippi River opposite Hartford	260
Missouri River opposite Fort Bellefontaine	261
Mississippi River at Chain of Rocks, near Missouri shore	253
Mississippi River at Chain of Rocks, near Illinois shore	246
Mississippi River at Chain of Rocks, at intake tower	250
St. Louis waterworks uptake	260
St. Louis waterworks outlet reservoir	261
Tap at city chemist's office	156
Harbor boat and special samples	47

After the close of this period weekly samples were taken until November 30, 1900, at the following points (1183–1184):

Samples of water collected from October 12 to November 30, 1900.

	Number of samples.
Lake Michigan	5
Desplaines River at Lockport	7
Illinois and Michigan Canal at Lockport	7
Desplaines River above entrance of Chicago drainage canal	7
Desplaines River at Ninth Street Bridge, Lockport	7
Bear Trap dam, Chicago drainage canal	7
Desplaines River at Joliet	7
Illinois River 3 miles above Peoria	7
Illinois River 3 miles above Pekin	7
Illinois River 3 miles above Grafton	9
Mississippi River 2 miles above Grafton	9
Mississippi River 1 mile above Alton	7
Mississippi River at Hartford	8
Missouri River at Fort Bellefontaine	7

Beginning with January 23 the samples were taken in duplicate and registered at the city chemist's office, one of the duplicate samples being analyzed there, while the other was analyzed in the laboratory of Washington University under the supervision of Prof. Edward H. Keiser. The chemical samples were sent to St. Louis by common carrier and were packed in ice.

From October 12, 1900, to September 30, 1901, daily samples were collected from Mississippi River at Chain of Rocks along the cross section previously defined. Daily samples were also taken from the outlet chamber of the St. Louis waterworks and from the tap at the city chemist's office. (661–662.)

The next period included the most thorough investigation and extended from October 1 to November 30, 1901. The work consisted

principally of a daily collection of samples at the following points (1247–1249):

Illinois and Michigan Canal at Bridgeport.
Drainage canal at Bridgeport.
Drainage canal at Bear Trap dam, Lockport.
Illinois and Michigan canal at Lockport.
Desplaines River above Bear Trap dam, Lockport.
Desplaines River at Ninth Street Bridge, Lockport.
Desplaines River at Ruby Street Bridge, Joliet.
Desplaines River at Brandon's bridge, Joliet.
Illinois River at La Salle.
Illinois River at Peoria, 3 miles above railroad bridge.
Illinois River at Pekin.
Illinois River at Kingston, 8 miles below Pekin.
Illinois River at Beardstown.
Illinois River at Grafton.
Mississippi River at Grafton.
Mississippi River at Alton.
Mississippi River at Hartford.
Mississippi River at Chain of Rocks, Illinois shore.
Mississippi River at Chain of Rocks, midstream.
Mississippi River at Chain of Rocks, waterworks intake.
Mississippi River at Chain of Rocks, Missouri shore.
Missouri River at Fort Bellefontaine.
St. Louis waterworks at outlet chamber.
Tap in city chemist's office, St. Louis.

Triweekly samples were collected from Lake Michigan at Chicago during this period and semiweekly samples from South Branch of Chicago River, near the Chicago and Alton Railroad bridge; also from Illinois River at Wesley, 3 miles below Peoria. Four sets of samples were taken above and below each of the following points along Missouri River: Omaha, Nebr.; Kansas City, Jefferson City, Hermann, and St. Charles, Mo. Two samples were collected from Missouri River at Wathena, Kans., and two samples from Kaw River, near Argentine, Kans. (1249–1250.)

During this period occasional cross-section samples were taken at such places as Pekin Bridge, Kingston, and Peoria, Illinois River; Joliet, Desplaines River; Alton, Chain of Rocks, and Hartford, Mississippi River; and Fort Bellefontaine, Missouri River. (1250.)

The last period of examination extended from December 1, 1901, to July 1, 1902, and represents the daily collection and analysis of samples from Mississippi River at the intake tower, Illinois shore, and Missouri shore at Chain of Rocks, from the outlet chamber of the St. Louis waterworks, and from the tap in the city chemist's office. Duplicate samples were sent to Professor Keiser for examination. (1289–1290.)

The witness prefaced his discussion of his analytical results by a review of some figures by Lyman E. Cooley on the flow of Illinois

River and its tributaries, in order that there might be a proper understanding of the effect of dilution.

Mr. Cooley gives the low-water flows in various parts of the Illinois River basin as follows: Desplaines River above Lockport in 1887, 256 cubic feet per minute; in 1879, 339 cubic feet per minute; Kankakee River, at Wilmington, during the twelve years from 1871 to 1883, 25,200 cubic feet per minute; Kankakee River at mouth, September 9, 1867, 27,377 cubic feet per minute; Fox River, at Ottawa, September 17, 1867, 31,539 cubic feet per minute. On this date the Mazon was practically dry. In Illinois River, at Morris, from May 13 to 28, 1887, the water was within 2 or 3 inches of the lowest stage since 1856, and it is doubtful if the amount exceeded 15,000 to 20,000 cubic feet per minute, or 250 to 350 cubic feet per second. At least 60 per cent of the water passing Morris in 1887 came from Lake Michigan by the Illinois and Michigan Canal, and probably one-half of the volume in ordinary low-water years comes from this source. A measurement made at La Salle by the canal authorities before the canal was deepened showed 37,900 cubic feet per minute, and doubtless Lake Michigan water has represented one-half of the volume passing in some recent low-water periods.

In 1888 Illinois River at the Henry dam ran less than 500 cubic feet per second for nine days, and at Copperas Creek the same amount for twenty days. The water at Copperas Creek was at or below the same level in 1887 for one hundred and seventeen days, in 1886 for eighteen days, and in 1879 for forty-four days; at Henry in 1877 for thirty days, in 1875 for forty-seven days, and in 1871 apparently for a longer period. The volume in 1888 was less than that discharged through the canal at Chicago for the same period. How much leakage there might have been through the dams at this time is unknown. In 1867 or earlier a measurement was made at La Salle of 633 cubic feet per second; in 1879, 1,566 cubic feet; and in 1887, 1,685 cubic feet. Part of the water in the last two measurements is chargeable to Lake Michigan.

It is probable that since the Bridgeport pumps were erected in 1883 over half of the minimum discharge above Havana and one-third of the minimum below the Sangamon has come from Lake Michigan. For the purposes of calculation the normal low-water volume is taken at 600 cubic feet per second for the upper section of the river. In 1887 60 per cent of the flow at Morris came from the Illinois and Michigan Canal, or, in other words, the natural flow of the Illinois above that point was only 8,000 cubic feet per minute, or 134 cubic feet per second. Let it be assumed for the purposes of calculation that, independent of Chicago sewage, the natural low-water volume for the section of the river above Havana is 300 [a] cubic feet

[a] Probably a misprint in the record for 200.

per second, and for the section below this point 800 cubic feet per second. This is the condition prior to the opening of the Chicago drainage canal. These figures show that the ratio of dilution of Chicago sewage in upper Illinois River prior to the opening of the drainage canal was 1:0.5, and in the lower division 1:2. (1163–1166.)

The witness stated that he had no personal data for Illinois River previous to the opening of the drainage canal in 1900. He referred, however, to the following reports which contain such data (1174):

Long, John H., Chemical investigations of the water supplies of Illinois: Rept. Illinois State Board of Health, pt. 1.

Palmer, A. W., Chemical survey of the water supplies of Illinois.

Long, John H., Advance notes of the sanitary investigation of Illinois River and its tributaries: Rept. Illinois State Board of Health, 1900.

Jordan, E. O., Some observations upon the bacterial self-purification of streams: Jour. Experimental Medicine, vol. 5, December 15, 1900.

Selected tables in these reports show, in the opinion of the witness—

1. That prior to the opening of the Chicago drainage canal Illinois River was polluted by the effluent of the Illinois and Michigan Canal to such an extent as to make the entire river a conduit for dilute sewage. The dilution of sewage between Utica and the mouth of the river was 1 to 2 in times of drought.

2. That while dilution, sedimentation, and oxidation are effective in reducing the quantity of characteristic sewage ingredients, they are not, in the case of Illinois River, sufficient to complete the process previous to the discharge of the river into the Mississippi.

3. That the tributaries of Illinois River are much purer than the main stream.

4. That during the interval between 1888 and 1899 there was a continual increase in the pollution of Illinois River while there was no corresponding increase in the pollution of its tributaries.

5. That it is only necessary to consider the increase in the amount of water pumped into the Illinois and Michigan Canal from Chicago River and discharged therefrom into Desplaines and Illinois rivers, and to recall the enormous growth of population and industries in Chicago, to obtain the explanation of the gradual conversion of Illinois River into an open sewer. (1174–1176.)

The witness then presented the results of his determinations of certain constituents in the water of Illinois and Mississippi rivers a short distance above Grafton, from September 6, 1899, to January 17, 1900. (1177–1178.)

TABLE 17.—*Maximum, minimum, and average results of analyses of water from Mississippi and Illinois rivers 3 miles above Grafton, September 6, 1899, to January 17, 1900.*

[Parts per million.]

	Illinois River.			Mississippi River.		
	Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.
Residue on evaporation:						
Total	510	330	413	450	195	285
Dissolved	460	240	340	280	130	205
Albuminoid ammonia	.763	.317	.553	.614	.394	.503
Free ammonia	.440	.091	.215	.134	.030	.069
Nitrites	.020	.003	.012	.008	.000	.002
Nitrates	1.1	.4	.8	.6	.2	.3
Oxygen consumed:						
Total	6	3.1	4.1	11.4	4.6	6.9
Dissolved	4.9	2.3	3.4	8.9	2.9	5.6
Chlorine	36	15	25	9	4	6

The witness called attention to the excess in nitrites, free ammonia, and chlorine of Illinois River over those of the Mississippi.

He then took up the discussion of analytical data procured from September 6 to December 4, 1899, concerning the character of water in Mississippi River between Grafton and Chain of Rocks, samples being taken from points specified on page 48. (1179–1180.)

The results of the analyses of semiweekly samples taken at the intake from October 16, 1899, to January 22, 1900, were then presented as shown in Table 18. (1180–1181.)

TABLE 18.—*Maximum, minimum, and average results of analyses of semiweekly samples from Mississippi River at St. Louis waterworks intake, October 16, 1899, to January 22, 1900.*

[Parts per million.]

	Maximum.	Minimum.	Average.
Free ammonia	0.138	0.008	0.0063(?)
Nitrates	.010	.000	.002
Nitrates	.8	.2	.4
Chlorine	27	9	17

The witness noted the wide variability of the water reported in the above table and assigned as a reason the "great fluctuations in the daily varying mixtures of Mississippi and Missouri river waters at the intake." The following conclusions were then given from the results of the work in 1899 (1181–1182):

1. The Illinois at its mouth was badly polluted.

2. The Mississippi above the mouth of Illinois River was of better quality.

3. The Mississippi between Grafton and St. Louis showed the effects of pollution from the Illinois, and on occasions when this water affected the intake at Chain of Rocks the St. Louis water supply became polluted.

4. Missouri River was generally purer than the Illinois above Grafton and than the Mississippi below the confluence with the Illinois.

The witness then proceeded to a discussion of the amount of Chicago sewage entering Illinois River from the Chicago drainage canal and the Illinois and Michigan canal. (1191–1196.)

He then presented ten charts, which were admitted in evidence and marked for identification "Complainant's Exhibits 52 to 61," inclusive. These charts contain in diagrammatic form the results of the determinations of nitrogen as free ammonia, nitrites, and nitrates, and of chlorine. The various records were grouped in different ways to illustrate the various points brought out by the witness, but as many of them constitute a duplication the charts will not be reproduced in this review. The results of the tests are set forth in Table 19.

TABLE 19.—*Results of sanitary analyses of water from designated points, January to October, 1900.*

NITROGEN AS FREE AMMONIA.

[Parts per million.]

Week beginning—	Bear Trap dam, Lockport.	Desplaines River at Joliet.	Illinois River at Averyville.	Illinois River at Grafton.	Mississippi River at Grafton.	Mississippi River above Alton.	Mississippi River at Hartford.	Missouri River at Fort Bellefontaine, Mo.	Mississippi River at Chain of Rocks, Missouri shore.	Mississippi River at Chain of Rocks, intake tower.	Mississippi River at Chain of Rocks, Illinois shore.
Jan. 23	.....	.....	2.80	1.40	0.105	0.682	0.740	0.140	.....	0.120	.....
Jan. 30	.....	.....	2.43	1.68	.175	1.052	.865	.112	.....	.230	.....
Feb. 6	.....	.....	1.24	1.15	.130	.830	.695	.290	.....	.280	.....
Feb. 13	.....	.....	.95	.81	.181	.507	.475	.137	.....	.175	.....
Feb. 20	.....	.....	1.27	.69	.280	.610	.575	.137	.....	.280	.....
Feb. 27	1.45	3.02	.92	.53	.260	.456	.426	.101	.....	.136	.....
Mar. 6	2.77	3.48	1.06	.24	.175	.190	.258	.190	.....	.201	.....
Mar. 13	.....	1.91	.55	.33	.393	.366	.383	.305	.....	.312	.....
Mar. 20	1.80	1.88	.41	.32	.428	.323	.331	.230	.....	.360	.....
Mar. 27	1.50	1.71	.50	.28	.362	.352	.312	.175	.....	.276	.....
Apr. 3	1.58	2.30	.50	.31	.378	.315	.298	.098	.....	.288	.....
Apr. 10	1.17	2.07	.44	.26	.280	.281	.297	.110	.....	.200	.....
Apr. 17	1.45	2.48	.54	.23	.160	.206	.200	.150	.....	.118	.....
Apr. 24	1.10	1.93	.35	.14	.160	.137	.130	.146	.....	.125	.....
May 1	1.48	2.41	.14	.12	.085	.115	.105	.200	.....	.107	.....
May 8	1.80	2.65	.28	.13	.086	.120	.100	.130	.....	.086	.....
May 15	1.18	2.40	.33	.14	.090	.106	.098	.143	.....	.113	.....
May 22	1.55	2.27	.28	.14	.080	.088	.072	.095	.....	.095	.....
May 29	1.23	2.68	.27	.07	.045	.075	.061	.110	.....	.067	.....
June 5	1.24	2.95	.27	.09	.055	.070	.060	.078	.....	.070	.....
June 12	1.60	2.60	.24	.07	.041	.042	.050	.084	.....	.065	.....
June 19	1.30	2.72	.25	.06	.059	.045	.053	.090	.....	.058	.....
June 26	1.53	3.12	.43	.08	.060	.068	.076	.115	.....	.090	.....
July 3	1.97	3.40	.23	.06	.047	.070	.067	.140	.....	.085	.....
July 10	1.53	2.75	.28	.08	.058	.062	.077	.125	.....	.082	.....
July 17	1.47	2.70	.44	.09	.072	.120	.100	.190	.....	.135	.....
July 24	1.67	2.62	.18	.10	.110	.135	.120	.208	.....	.220	.....
July 31	1.30	2.05	.17	.10	.111	.110	.110	.150	.....	.140	.....
Aug. 7	1.42	2.16	.16	.10	.106	.091	.093	.110	.....	.100	.....
Aug. 14	1.25	2.36	.18	.10	.096	.081	.087	.070	.....	.0.5	.....
Aug. 21	1.61	3.70	.22	.08	.090	.100	.121	.138	.....	.105	.....
Aug. 28	1.42	2.05	.19	.08	.079	.082	.068	.140	.....	.115	.....
Sept. 4	1.47	3.05	.15	.07	.072	.078	.068	.180	.....	.125	.....
Sept. 11	2.48	5.03	.17	.05	.068	.078	.088	.095	.....	.080	.....
Sept. 18	2.05	6.21	.21	.12	.090	.062	.097	.120	.....	.082	.....
Sept. 25	1.85	3.27	.70	.10	.086	.099	.093	.130	.....	.085	.....
Oct. 2	1.20	2.11	1.35	.10	.107	.120	.120	.170	.....	.120	.....

19.—*Results of sanitary analyses of water from designated points, January to October, 1900*—Continued.

NITROGEN AS NITRITES.

Bear Trap dam, Lockport.	Desplaines River at Joliet.	Illinois River at Averyville.	Illinois River at Grafton.	Mississippi River at Grafton.	Mississippi River above Alton.	Mississippi River at Hartford.	Missouri River at Fort Bellefontaine, Mo.	Mississippi River at Chain of Rocks, Missouri shore.	Mississippi River at Chain of Rocks, intake tower.	Mississippi River at Chain of Rocks, Illinois shore.
.....	.....	0.029	0.031	0.005	0.021	0.014	0.007	0.007	0.006	0.017
.....	.....	.042	.039	.002	.028	.026	.005	.005	.008	.021
.....	.....	.035	.021	.007	.020	.019	.008	.008	.012	.025
.....	.....	.032	.019	.006	.015	.014	.008	.008	.013	.012
.....	.....	.038	.023	.012	.021	.019	.010	.010	.014	.018
.....	0.033	.027	.030	.011	.029	.023	.016	.016	.014	.018
0.048	.050	.033	.021	.010	.022	.019	.015	.015	.016	.015
.065	.061	.019	.018	.010	.019	.014	.017	.017	.017	.017
.043	.048	.020	.019	.008	.020	.019	.015	.015	.014	.017
.085	.079	.016	.015	.007	.017	.018	.015	.015	.014	.019
.098	.093	.020	.023	.017	.024	.026	.011	.011	.020	.027
.060	.056	.034	.035	.024	.037	.034	.008	.008	.022	.031
.074	.060	.061	.046	.016	.042	.049	.012	.012	.019	.031
.043	.027	.077	.050	.025	.042	.040	.011	.011	.019	.028
.019	.026	.072	.040	.004	.022	.022	.011	.011	.010	.017
.042	.031	.122	.039	.008	.027	.028	.010	.010	.013	.015
.038	.035	.084	.057	.013	.038	.036	.011	.011	.011	.017
.009	.017	.082	.061	.008	.031	.027	.005	.006	.010	.019
.015	.032	.122	.056	.004	.014	.013	.004	.005	.008	.009
.027	.027	.133	.016	.004	.006	.005	.003	.004	.005	.005
.004	.033	.147	.015	.005	.007	.005	.004	.005	.005	.005
.006	.034	.139	.018	.007	.009	.009	.003	.004	.003	.004
.006	.036	.137	.046	.007	.030	.026	.002	.003	.002	.002
.006	.057	.159	.022	.006	.016	.013	.002	.003	.003	.004
.012	.....	.158	.025	.006	.016	.012	.002	.003	.002	.005
.005	.032	.213	.033	.008	.022	.017	.003	.003	.003	.008
.007	.042	.119	.047	.008	.021	.018	.008	.008	.006	.015
.004	.033	.149	.032	.006	.012	.010	.005	.004	.004	.008
.009	.049	.159	.030	.004	.014	.012	.006	.006	.004	.001
.023	.061	.206	.043	.006	.021	.017	.006	.006	.004	.015
.009	.046	.178	.020	.011	.015	.014	.005	.004	.004	.009
.007	.031	.142	.016	.003	.009	.008	.004	.004	.003	.007
.009	.107	.155	.018	.006	.011	.009	.006	.003	.003	.007
.002	.027	.094	.023	.005	.012	.011	.002	.002	.003	.009
.008	.035	.084	.033	.006	.012	.011	.003	.003	.004	.009
.011	.026	.106	.043	.006	.014	.014	.004	.003	.004	.011
.011	.051	.145	.042	.008	.019	.017	.008	.006	.006	.013

TABLE 19.—*Results of sanitary analyses of water from designated points, January to October, 1900*—Continued.

NITROGEN AS NITRATES.

Week beginning—	Bear Trap dam, Lockport.	Des plaines River at Joliet.	Illinois River at Averyville.	Illinois River at Grafton.	Mississippi River at Grafton.	Mississippi River above Alton.	Mississippi River at Hartford.	Missouri River at Fort Bellefontaine.	Mississippi River at Chain of Rocks, Missouri shore.	Mississippi River at Chain of Rocks, intake tower.	Mississippi River at Chain of Rocks, Illinois shore.
Jan. 23	.....	.....	2.95	2.55	0.50	1.35	1.50	0.35	.....	0.60	.....
Jan. 30	.....	.....	1.85	1.85	.60	1.20	1.40	.35	.....	.50	.....
Feb. 6	.....	.....	1.55	2.05	.70	1.35	1.15	.55	.....	.65	.....
Feb. 13	.....	.....	1.25	1.15	.50	.85	.95	.45	.....	.80	.....
Feb. 20	.....	.....	1.20	1.05	.50	1.00	.95	.35	.....	.55	.....
Feb. 27	0.25	0.25	1.35	1.45	.70	.95	1.10	.60	.....	.70	.....
Mar. 6	.25	.30	1.00	.80	.60	.70	.75	.80	.....	.80	.....
Mar. 13	.50	.50	.82	1.05	.70	1.05	1.00	1.35	.....	1.10	.....
Mar. 20	.30	.60	.95	1.15	.60	1.10	1.15	1.10	.....	.90	.....
Mar. 27	.20	.25	1.00	1.00	.20	.75	.95	.95	.....	.60	.....
Apr. 3	.30	.35	1.15	1.10	.60	1.05	.90	.35	.....	.55	.....
Apr. 10	.35	.30	1.30	1.05	.80	1.15	1.10	.50	.....	.70	.....
Apr. 17	.35	.40	1.30	.....	.60	1.05	1.10	.55	.....	.55	.....
Apr. 24	.40	.30	.80	.85	.50	.90	.80	.65	.....	.60	.....
May 1	.20	.20	.60	.65	.20	.65	.50	.60	.....	.45	.....
May 8	.25	.25	.67	.45	.20	.35	.40	.50	.....	.45	.....
May 15	.20	.10	.80	.55	.33	.50	.44	.50	.....	.55	.....
May 22	.10	.10	.55	.45	.20	.40	.35	.35	.....	.45	.....
May 29	.17	.15	.55	.65	.20	.40	.35	.35	.....	.35	.....
June 5	.50	.05	.75	.55	.05	.40	.35	.30	.....	.30	.....
June 12	0	.05	.70	.60	.10	.40	.30	.20	.....	.30	.....
June 19	0	0	.75	.65	0	.45	.40	.20	.....	.20	.....
June 26	0	0	.40	.45	.15	.40	.35	.25	.....	.25	.....
July 3	0	0	.30	.40	.05	.30	.20	.20	.....	.20	.....
July 10	0	0	.40	.40	.10	.25	.25	.25	.....	.25	.....
July 17	0	0	.50	.40	.15	.30	.30	.20	.....	.25	.....
July 24	0	0	.55	.46	.25	.30	.30	.40	.....	.40	.....
July 31	.15	.05	.56	.35	.20	.33	.25	.30	.....	.35	.....
Aug. 7	.12	.08	1.25	.95	.15	.45	.35	.40	.....	.45	.....
Aug. 14	.12	.12	1.30	.80	.10	.30	.30	.30	.....	.40	.....
Aug. 21	.15	.13	1.05	.95	.45	.75	.65	.75	.....	.45	.....
Aug. 28	.10	.19	1.35	1.15	.45	.80	.75	.90	.....	.75	.....
Sept. 4	.15	.24	1.60	1.00	.55	.80	.75	.95	.....	.75	.....
Sept. 11	.12	.13	1.35	1.25	.45	.70	.65	.70	.....	.55	.....
Sept. 18	.11	.27	1.75	1.00	.20	.50	.45	.65	.....	.55	.....
Sept. 25	.15	.15	1.50	1.20	.30	.60	.55	.85	.....	.75	.....
Oct. 2	0	.04	1.70	1.20	.40	.65	.50	.85	.....	.70	.....

TABLE 19.—*Results of sanitary analyses of water from designated points, January to October, 1900*—Continued.

CHLORINE.

Week beginning—	Bear Trap dam, Lockport.	Desplaines River at Joliet.	Illinois River at Averyville.	Illinois River at Grafton.	Mississippi River at Grafton.	Mississippi River at Alton.	Mississippi River at Hartford.	Missouri River at Fort Bellefontaine, Mo.	Mississippi River at Chain of Rocks, Missouri shore.	Mississippi River at Chain of Rocks, intake tower.	Mississippi River at Chain of Rocks, Illinois shore.
Jan. 23	.....	.....	23	18	8	12	12	28	26	23	10
Jan. 30	.....	.....	21	21	9	15	14	29	25	25	12
Feb. 6	.....	.....	17	14	8	12	11	22	23	16	12
Feb. 13	.....	.....	12	11	6	9	8	33	27	16	8
Feb. 20	.....	.....	15	10	6	9	9	23	22	14	10
Feb. 27	15	26	12	10	6	9	8	21	21	18	8
Mar. 6	15	32	14	7	6	7	7	12	22	10	8
Mar. 13	19	19	8	7	5	6	6	11	11	9	6
Mar. 20	15	19	6	6	4	7	7	12	13	8	6
Mar. 27	18	18	8	6	5	7	7	16	15	8	7
Apr. 3	18	23	8	7	5	7	7	18	18	10	7
Apr. 10	14	22	9	7	5	7	7	11	14	9	7
Apr. 17	16	27	11	8	5	7	7	12	12	9	7
Apr. 24	13	19	11	8	4	7	7	13	12	10	7
May 1	13	19	12	9	4	8	8	14	14	10	7
May 8	13	22	15	10	4	8	7	12	13	9	7
May 15	11	19	17	9	4	10	9	14	12	10	9
May 22	12	18	14	7	4	9	9	13	12	11	8
May 29	11	20	11	12	4	9	7	13	12	11	8
June 5	13	23	16	12	4	9	8	14	12	12	9
June 12	15	23	16	14	5	9	8	11	11	10	10
June 19	13	21	20	12	5	9	9	11	11	11	9
June 26	12	22	19	15	5	11	10	9	12	9	9
July 3	17	29	20	16	6	13	11	10	10	10	9
July 10	15	26	22	15	7	12	11	10	10	10	9
July 17	13	23	29	14	5	10	9	12	12	11	9
July 24	15	24	23	19	3	9	9	10	10	9	8
July 31	14	21	23	21	5	10	10	14	11	10	9
Aug. 7	14	20	19	19	4	12	10	18	13	12	9
Aug. 14	14	22	20	19	6	12	11	20	15	13	10
Aug. 21	17	27	20	13	3	8	8	14	13	10	7
Aug. 28	14	20	19	15	4	10	8	23	18	17	9
Sept. 4	12	28	19	15	4	10	10	22	22	17	10
Sept. 11	20	42	18	16	4	10	9	17	15	13	9
Sept. 18	17	55	22	15	3	8	9	19	14	13	8
Sept. 25	15	27	25	16	3	8	6	21	18	15	6
Oct. 2	11	20	27	16	2	6	6	13	12	9	5

In discussing the results set forth in Table 19 the witness stated that the determinations in samples taken from the Chicago drainage canal at Lockport, from Desplaines River at Joliet, and from Illinois River 3 miles above Peoria show that the water undergoes little change and practically no improvement in passing from the first to the third point and that the high free ammonia and nitrites which are found to persist in the Peoria water present unmistakable evidence that it has not yet reached its final process of purification. The witness called attention to the alleged coincident fluctuations which take place at all three points. Whenever there is an increase in the proportion of any or all of the ingredients determined at Lockport there follows in due time a corresponding increase in the same ingredients at Joliet and Peoria. This was mentioned by the witness as proving absolutely that the character of the water at Peoria is governed by that of the drainage canal. (1204–1207.)

Comparing the results of samples taken from Illinois River above Peoria and above Grafton, the witness stated that after the opening of the canal there was an increase in chlorine from an average of 21 to 28 parts per million at Peoria and from 15 to 23 parts at Grafton, while the fluctuations in nitrites and free ammonia correspond. During the summer months the increased anaerobic action below Peoria causes divergence in the figures. (1207–1209.)

The witness then testified with reference to the effect of Peoria sewage on Illinois River. The total daily discharge from Peoria sewers, based on a poulation of 56,100 and 150 gallons of sewage per capita per day, would be 8,415,000 gallons, or 1,122,000 cubic feet. As at the time of testimony the sewerage system at this city had been extended to serve only 47 per cent of the population, the actual discharge based on the above factors would be 527,000 cubic feet per day. The minimum flow of Illinois River at Peoria, according to the measurements of Lyman E. Cooley, was, before the opening of the drainage canal, 72,000 cubic feet per minute; the discharge of the drainage canal is 250,000 cubic feet per minute, so that the minimum flow of Illinois River at Peoria after the opening of the canal was 322,000 cubic feet per minute. The witness then used the value 1,122,000 cubic feet per day, or 779 cubic feet per minute, to represent the flow of sewage from Peoria, notwithstanding the fact that he had testified that the real flow of sewage was only 47 per cent of this amount. Comparing this calculated sewage flow with the minimum flow of the river, he deduced a ratio of dilution 1 : 413. He then expressed his opinion that were the water of Illinois River as it came down to Peoria comparatively pure instead of being highly polluted, the effect of this dilution of Peoria sewage would be such that the river would purify itself after running 25 to 50 miles. Therefore the effect of Peoria sewage on Illinois River, so far as the St. Louis water supply is concerned, is negligible. (1211–1215.)

The witness claimed that the figures show Illinois River above Grafton to be particularly unstable in comparison with the Mississippi above the mouth of the Illinois by reason of fermentative changes which were taking place. Along with these figures were given the relative gage heights in both streams, which supported the witness's contention that the variations taking place in the waters of the two rivers are not due to any flood effects, because there were no significant relative differences in the stages of the rivers during the period of examination. During the latter part of February and the month of March there was a rise in both rivers, resulting in an increase in the free ammonia; but after the rivers had receded to ordinary stage the difference in the free ammonia practically disappeared. Throughout the year the nitrites, nitrates, and chlorine were much higher in the Illinois than in the Mississippi. (1209–1211.)

Concerning the results of examination of water from Illinois River 3 miles above Grafton and from Mississippi River above Grafton, above Alton, and at Hartford, the witness claimed that the evidence shows that the fluctuations in amounts of different ingredients in Illinois River samples are accompanied by similar fluctuations in samples from Mississippi River above Alton and at Hartford, while the samples of Mississippi River above Grafton show no such relation, demonstrating, in his opinion, that Illinois River pollution markedly affects Mississippi River at Alton and Hartford and excluding the possibility that such an effect might have arisen in the Mississippi above the mouth of the Illinois. (1215–1217.)

Continuing, the witness discussed the resemblance appearing between the water from Missouri River at Fort Bellefontaine and that from Mississippi River at Chain of Rocks, near the Missouri shore.

He then took up the results of the examinations made at three points along the cross section of Mississippi River at Chain of Rocks, and from a consideration of the total solids, chlorine, and nitrites advanced the idea that the water entering the intake tower in the middle of the river partakes of the character of that from either shore and is generally a definite mixture of both. It was pointed out that Missouri River water contains a higher proportion of total solids and chlorine than that from Mississippi or Illinois rivers, while the nitrites in the two latter streams are generally higher than in the former. When the Missouri is high and the Mississippi low the water from the former predominates in the intake tower, and when the Mississippi is higher than the Missouri the reverse condition is maintained. The witness further explained that the occurrence of a higher proportion of chlorine in the Missouri water is due to the influx of water from Kaw River, which drains extensive salt countries in Kansas, while the high proportion of total solids in the Missouri water is due to the character of the soil drained and the erosion caused therein, and he asserted without qualification that although Missouri River water contains a higher proportion of albuminoid ammonia it is not accompanied by high free ammonia and nitrites, proving that the organic matter is derived from vegetable rather than from animal sources. (1217–1225.)

The witness then presented a series of tables designed to show the percentage of Missouri River and Mississippi River water entering the intake tower during the period from January 24 to October 10, 1900, based on the determinations of total solids in samples taken from Mississippi River at Hartford, the lowest sampling point above the mouth of Missouri River; from the Missouri at Fort Bellefontaine; and from the intake tower at the waterworks. These values being given, the percentages of water from each river at the intake are, according to the witness, accurately and easily calculated, as shown in Table 20. (1226–1240.)

It will be observed that when the value for total solids at the is intermediate between those at the other two points the perce are calculated on the basis of an equal mixture of the two When this value is greater or less than the other two, howeve assumed that all the water comes from the river, showing tively the greater or less content of total solids.

TABLE 20.—*Total solids in samples collected at Fort Bellefontaine, Hartford, Louis waterworks intake, and percentages of Missouri River and Mississipp water entering intake, January 24 to October 10, 1900.*

Date.	Total solids (parts per million).					Percentag ter ent take fro
	Fort Bellefontaine.	Intake.	Hartford.	Difference between— Fort Bellefontaine and Hartford.	Difference between— Intake and Hartford.	Missouri River.
Jan. 24	800	720	500	300	220	73
25	740	670	580	160	90	56
26	710	685	380	390	305	78
27	710	670	390	320	280	87
28	690	690	460	0	230	100
29	720	570	400	320	170	53
30	700	590	340	360	250	69
31	640	580	370	270	210	78
Feb. 2	535	450	330	205	120	58
3	500	450	380	120	70	58
4	540	490	410	130	80	62
5	470	460	320	150	140	93
7	1,540	400	400	1,140	0	0
9	1,500	1,290	1,230	270	60	22
10	1,160	1,430	1,680	520	200	38
12	1,050	1,120	1,200	150	80	53
13	1,020	1,220	1,590	570	370	65
14	770	920	1,430	660	510	77
15	500	600	1,300	800	700	88
16	500	540	2,325	1,825	1,785	98
Mar. 4	690	640	450	240	190	79
8	3,430	2,940	1,130	2,300	1,810	79
9	2,435	1,900	1,180	1,255	720	57
10	2,520	2,040	1,060	1,460	980	67
12	3,410	2,340	1,115	2,295	1,225	53
13	3,940	3,100	1,420	2,520	1,680	67
14	4,050	3,180	1,485	2,325	1,895	81
15	4,050	3,180	1,310	2,740	1,870	68
17	3,590	2,680	1,210	2,290	1,410	62
18	3,430	2,380	1,240	2,190	1,140	52
20	2,370	1,600	1,250	1,120	350	31
21	2,010	1,890	1,420	590	470	80
22	2,375	1,205	1,091	1,284	114	9
23	1,575	891	806	769	85	11
24	1,470	678	830	.....	.....	0
25	1,233	728	765	.....	.....	0
26	1,142	640	831	.....	.....	0
27	1,363	528	670	.....	.....	0
28	1,142	554	647	.....	.....	0
29	928	627	439	489	188	38
31	1,010	590	600	.....	.....	0
Apr. 1	1,180	590	510	670	80	12
2	1,280	870	460	840	410	50
3	1,400	880	480	920	400	44
4	1,510	860	480	1,030	380	37
5	1,540	935	455	1,085	480	44
6	1,530	1,200	480	1,050	720	68
7	1,570	1,595	630	.....	.....	100
8	1,785	1,220	545	1,240	675	55
9	1,875	1,235	545	1,330	690	52
10	1,735	1,300	480	1,255	820	65
11	1,675	1,150	500	1,175	650	55
12	1,860	1,085	455	1,405	630	45
13	1,965	1,240	450	1,515	790	52
14	2,955	2,110	415	2,540	1,695	67

–Total solids in samples collected at Fort Bellefontaine, Hartford, and St. terworks intake, and percentages of Missouri River and Mississippi River ring intake, January 24 to October 10, 1900—Continued.

Date.	Total solids (parts per million).					Percentage of water entering intake from—	
	Fort Bellefontaine.	Intake.	Hartford.	Difference between— Fort Bellefontaine and Hartford.	Difference between— Intake and Hartford.	Missouri River.	Mississippi River.
.....	3,402	3,542	376	.....	.....	100	0
.....	1,861	2,048	.....	.....	.....	100	0
.....	3,604	1,842	401	3,203	1,441	45	55
.....	2,395	1,807	424	1,871	1,383	70	30
.....	2,410	1,488	410	2,000	1,078	54	46
.....	2,384	1,309	425	1,959	884	45	55
.....	2,300	1,611	458	1,848	1,153	63	37
.....	4,374	1,342	520	3,854	822	21	79
.....	1,987	1,657	493	1,494	1,154	78	22
.....	1,755	1,354	615	1,140	739	65	35
.....	1,938	1,488	1,444	494	44	9	91
.....	1,574	1,375	469	1,105	906	82	18
.....	2,000	1,455	521	1,479	934	63	37
.....	1,730	1,310	440	1,290	870	68	32
.....	1,438	1,240	458	980	782	80	20
.....	1,655	1,245	455	1,200	790	66	34
.....	1,665	1,260	420	1,245	840	67	33
.....	1,845	1,435	445	1,400	990	71	29
.....	2,287	1,535	380	1,887	1,155	61	39
.....	2,600	1,485	415	2,185	1,070	49	51
.....	2,880	1,685	1,235	1,645	430	26	74
.....	2,110	1,485	510	1,600	955	60	40
.....	1,951	1,449	1,091	860	358	42	56
.....	1,913	1,390	545	1,368	845	62	38
.....	2,013	1,300	555	1,458	745	51	49
.....	1,696	1,202	491	1,205	717	59	41
.....	1,885	1,258	448	1,437	810	56	44
.....	2,198	1,884	453	1,745	1,431	82	18
.....	3,563	2,147	410	3,163	1,737	55	45
.....	3,010	2,120	420	2,590	1,700	66	34
.....	2,380	1,960	415	1,965	1,545	79	21
.....	2,495	1,930	450	2,045	1,480	72	28
.....	2,335	2,050	405	2,430	1,645	68	32
.....	2,615	2,396	545	2,070	1,851	90	10
.....	2,160	1,945	505	1,655	1,440	87	13
.....	2,340	1,985	490	1,850	1,495	81	19
.....	2,280	2,033	546	1,734	1,487	86	14
.....	2,358	2,032	565	1,793	1,467	82	18
.....	2,136	2,007	526	1,610	1,481	83	17
.....	2,204	1,917	575	1,689	1,402	83	17
.....	2,283	1,834	457	1,826	1,377	75	25
.....	2,120	1,805	502	1,618	1,303	81	19
.....	1,743	1,918	440	1,303	1,478	100	0
.....	2,280	2,122	420	1,805	1,702	94	6
.....	3,480	2,255	380	2,090	1,865	89	11
.....	2,290	2,290	435	.....	.....	100	0
.....	2,200	2,090	410	1,790	1,680	94	6
.....	2,580	2,005	390	2,190	1,615	74	26
.....	2,280	2,180	335	1,945	1,845	95	5
.....	2,170	2,285	430	1,740	.....	100	0
.....	2,455	2,155	460	1,995	1,695	85	15
.....	2,360	2,105	435	1,925	1,660	86	14
.....	2,355	1,950	410	1,945	1,540	79	21
.....	2,375	1,825	390	1,985	1,433	72	28
.....	2,405	2,010	380	2,025	1,630	81	19
.....	2,475	1,935	330	2,145	1,605	75	25
.....	1,950	1,858	340	1,610	1,515	94	6
.....	2,015	2,030	425	.....	.....	100	0
.....	2,315	2,215	595	1,720	1,620	94	6
.....	4,315	3,955	320	3,995	3,635	91	9
.....	3,538	3,730	375	.....	.....	100	0
.....	2,562	2,935	335	.....	.....	100	0
.....	2,326	2,657	324	.....	.....	100	0
.....	2,545	2,412	340	2,205	2,072	94	6
.....	2,189	2,280	345	.....	.....	100	0
.....	2,179	2,080	335	1,844	1,670	91	9
.....	2,210	2,100	305	1,905	1,795	94	6

TABLE 20.—*Total solids in samples collected at Fort Bellefontaine, Hartford, and Louis waterworks intake, and percentages of Missouri River and Mississippi R water entering intake, January 24 to October 10, 1900*—Continued.

Date.	Total solids (parts per million).					Percentage of water entering intake from—	
	Fort Bellefontaine.	Intake.	Hartford.	Difference between— Fort Bellefontaine and Hartford.	Difference between— Intake and Hartford.	Missouri River.	Mi[illegible]
June 22	3,258	3,055	315	2,943	2,740	93	
23	3,683	3,910	363	.....	.....	100	
24	3,205	4,184	471	.....	.....	100	
25	3,506	3,892	471	.....	.....	100	
26	3,330	3,503	.....	.....	.....	100	
27	3,170	3,156	470	2,700	2,685	99	
28	3,325	2,870	455	2,870	2,415	84	
29	2,760	2,805	405	.....	.....	100	
30	2,686	2,805	405	.....	.....	100	
July 1	2,440	2,770	380	.....	.....	100	
2	2,515	2,867	345	.....	.....	100	
3	2,115	2,800	325	.....	.....	100	
4	2,782	2,873	335	.....	.....	100	
5	3,945	3,000	330	3,615	2,660	74	
6	3,400	4,175	331	.....	.....	100	
7	3,125	3,193	364	.....	.....	100	
8	3,060	3,234	864	.....	.....	100	
9	3,435	3,490	343	.....	.....	100	
10	3,822	3,400	330	3,492	3,070	88	
11	2,690	2,855	320	.....	.....	100	
12	2,430	2,655	540	.....	.....	100	
13	2,175	2,415	310	.....	.....	100	
14	1,970	2,210	290	.....	.....	100	
15	1,450	2,100	270	.....	.....	100	
16	2,433	2,315	280	2,155	2,135	94	
17	2,575	2,405	415	2,160	1,990	92	
18	2,360	1,880	310	2,050	1,570	77	
19	2,415	2,300	327	2,088	1,973	95	
20	2,293	2,050	610	1,683	1,440	86	
21	2,020	1,800	370	1,650	1,430	87	
22	1,895	2,132	380	.....	.....	100	
23	2,780	2,760	344	2,436	2,416	99	
24	3,885	3,210	310	3,575	2,900	81	
25	4,580	3,420	335	4,245	3,090	73	
26	3,791	3,277	408	3,383	2,869	85	
27	3,157	2,500	480	2,677	2,020	76	
28	2,730	2,371	450	2,280	1,921	84	
30	2,310	1,995	408	1,902	1,587	83	
31	2,061	1,972	512	1,549	1,460	94	
Aug. 1	2,127	1,795	522	1,605	1,273	79	
2	1,725	1,807	495	1,230	1,312	100	
3	1,975	1,693	455	1,520	1,238	82	
4	1,812	1,630	382	1,430	1,248	87	
5	1,622	1,339	340	1,282	999	78	
6	1,530	1,393	315	1,215	1,078	89	
7	1,530	1,045	302	1,228	743	61	
8	1,294	1,069	305	989	764	77	
9	1,243	1,008	305	937	703	75	
10	1,226	990	289	937	701	75	
11	1,220	970	240	980	730	75	
12	1,082	935	280	802	655	81	
13	1,060	890	292	768	589	78	
14	1,110	904	300	810	604	75	
15	1,000	860	270	730	590	81	
16	1,053	860	234	730	576	75	
17	1,053	860	284	769	575	67	
18	960	890	260	700	630	90	
19	1,343	1,061	283	1,060	778	73	
20	1,482	1,305	318	1,164	988	85	
21	1,785	1,305	405	1,380	900	65	
22	1,845	1,525	665	1,180	860	73	
23	1,760	1,445	685	1,075	760	71	
24	1,610	1,470	688	922	782	85	
25	1,556	1,320	584	972	736	76	
26	1,556	1,320	584	972	736	76	
27	1,410	1,358	538	872	820	94	
28	1,595	1,422	445	1,150	977	85	
29	1,565	1,379	420	1,145	951	83	

Total solids in samples collected at Fort Bellefontaine, Hartford, and St. works intake, and percentages of Missouri river and Mississippi River ng intake, January 24 to October 10, 1900—Continued.

e.	Total solids (parts per million).					Percentage of water entering intake—	
	Fort Bellefontain=.	Intake.	Hartford.	Difference between— Fort Bellefontaine and Hartford.	Difference between— Intake and Hartford.	Missouri River.	Mississippi River.
.....	1,881	1,125	375	1,508	750	50	50
.....	1,881	1,125	375	1,506	750	50	50
.....	1,376	1,315	430	946	885	94	6
.....	1,460	1,450	420	1,040	1,030	99	1
.....	1,610	1,414	445	1,165	969	82	18
.....	1,930	1,489	365	1,565	1,124	72	28
.....	1,600	1,545	370	1,230	1,175	96	4
.....	1,635	1,436	354	1,281	1,082	84	16
.....	1,570	1,308	352	1,218	1,056	87	13
.....	1,430	1,240	340	1,090	900	83	17
.....	1,492	1,033	359	1,143	674	60	40
.....	1,305	1,048	340	965	708	73	27
.....	1,213	931	348	865	583	67	33
.....	1,110	896	298	812	598	74	26
.....	1,270	900	345	945	555	60	40
.....	1,186	900	330	856	570	67	33
.....	1,230	853	300	930	553	60	40
.....	1,210	864	340	870	524	60	40
.....	1,428	970	311	1,117	659	56	44
.....	2,200	1,380	311	1,889	1,069	57	43
.....	3,230	1,900	313	2,917	1,597	54	46
.....	2,985	1,920	327	2,658	1,593	60	40
.....	3,116	1,980	330	2,786	1,650	59	41
.....	2,558	1,836	360	2,198	1,476	67	33
.....	2,365	1,640	320	3,045	1,320	65	35
.....	1,970	1,500	580	1,390	920	66	34
.....	1,870	1,325	350	1,520	975	64	36
.....	1,785	1,330	605	1,180	925	68	32
.....	1,840	1,373	400	1,440	973	68	32
.....	1,847	1,357	444	1,403	913	65	35
.....	1,990	1,320	365	1,625	965	59	41
.....	2,960	1,990	448	2,512	1,542	61	39
.....	2,920	1,332	455	2,465	877	36	64
.....	2,677	2,036	394	2,283	1,642	72	28
.....	2,480	1,895	376	2,104	1,519	72	28
.....	3,095	1,937	370	2,725	1,567	58	42
.....	2,578	1,878	357	2,221	1,521	68	32
.....	2,605	2,095	355	2,250	1,740	77	23
.....	2,807	2,165	370	2,437	1,791	74	26

lesignated as Complainant's Exhibit No. 60, showing dia- ally the records of typhoid fever in St. Louis for 1895 to sive, and for 1900 in connection with the percentage of River water entering the intake from January 24 to Octo- 0, calculated from the total solids as described, was then y the witness. He claimed that a great increase in the of Mississippi River water entering the intake in 1900 d in due time, a proper period of incubation being allowed, ase in the typhoid rate of the city. He further remarked increase was very much higher than the average for the previous. He called attention to the variations in the e of 1900. (1240–1242.)

According to these calculations it appears that on or about February 6 100 per cent of Mississippi River water entered the intake tower, followed by 90 per cent February 21. During the week beginning February 20 there was an increase in the number of cases reported, and it reached a maximum of 40 during the week ending March 13. There was a sharp decline after this and the rate remained comparatively low until the week ending September 4, when there was a considerable increase, continuing until a maximum of 102 cases was reached during the week ending October 2, after which there was another sharp decline. This latter increase was preceded by an increase in the proportion of Mississippi River water entering the intake, but the percentage was not at any time previous to the apex of the outbreak greater than 50, and this occurred only on two days—August 30 and 31. Inasmuch as the chart is not presented in this review, it is fair to state that immediately after the outbreak which reached its height March 13 and declined sharply thereafter, the rate remaining low for the remainder of the summer, a larger proportion of Mississippi River water entered the intake than at any other time during the investigation. March 15 the proportion of Mississippi water began to increase, reaching 100 per cent March 24 and remaining practically at that point for a week. This was not, however, followed by any increase in typhoid, but, on the contrary, the rate declined and remained low during the subsequent heavy influx of Mississippi water between April 17 and 26.

The witness then discussed the chart representing diagrammatically the comparison of samples of water from the intake tower with those taken from the reservoir after two days' sedimentation and with those from the tap in the city chemist's office. It was noted that, although the water had passed through the sedimentation reservoir and 85 per cent of its suspended matter had been removed its condition as it left the reservoir and was drawn from the tap was not greatly improved over its condition at the intake tower. A marked increase in the free ammonia and nitrites in the intake water was followed by similar increase in these ingredients at the two other points. Therefore, in the opinion of the witness, from the standpoint of actual purification the reservoir can not be said to be highly effective.

Doctor Teichmann then called attention to an unusual rise in the proportion of free ammonia and nitrites in the early part of 1900, and stated that none of the analytical results on record, representing analyses made during twenty years previous, had shown so remarkable a quantity of free ammonia and nitrites at the intake tower, the reservoir, or the tap. Such an increase was marked all along Illinois River to its mouth and at the various sampling points along Mississippi River down to the intake tower. No corresponding increas

occurred in the water of Mississippi River above the mouth of the Illinois nor in the Missouri, and all of it occurred directly after the opening of the drainage canal in January, 1900. The analyses of samples taken at the various points in 1899 previous to the opening of the canal and in 1900 after such opening being compared, the general result was shown to be that there were evidences of increased pollution all along the course, from Desplaines River at Lockport even down to the intake tower and the tap in the laboratory of the city chemist. (1242–1246.)

The testimony of the witness was then directed to investigations subsequent to that of 1900. He stated that a number of samples were collected between October 12 and November 30, 1901, from points in Illinois River, but inasmuch as they were not collected regularly, the results were not included in the evidence. Samples were collected daily during these two months from Mississippi River along a cross section at Chain of Rocks, near the Missouri shore, at the intake tower, and near the Illinois shore. The results show that the water along the Illinois shore was at all times more polluted than that along the Missouri shore, while that at the intake was a mixture of the two, partaking of the nature of one side or the other according to the relative heights of Mississippi and Missouri rivers. (1246–1247.)

The witness presented a series of charts which were admitted in evidence and marked for identification as Complainant's Exhibits Nos. 62 to 70, inclusive. The charts contain statements in diagrammatic form of weekly average results of analyses of water during this period from the various sampling points mentioned, these averages being combined in a series intended to bring out more clearly the points which the witness considered important in establishing the case of the complainant. The results are included in Table 21.

TABLE 21.—*Weekly average results of analyses of water at various points, October and November, 1901.*

FREE AMMONIA.

Sampling point.	Week ending—							
	Oct. 4.	Oct. 11.	Oct. 18.	Oct. 25.	Nov. 1.	Nov. 8.	Nov. 15.	Nov. 22.
Illinois and Michigan Canal at Bridgeport	9.70	14.25	11.72	12.80	10.60	14.35	16.55	21.80
Illinois and Michigan Canal at Lockport	20.82	17.54	17.02	15.25	17.75	22.12	18.70	22.48
Chicago drainage canal at Bridgeport	.95	.97	.79	1.06	1.18	2.37	.55	.09
Chicago drainage canal at Bear Trap dam	1.32	1.33	1.17	1.34	1.28	1.24	.95	1.11
Desplaines River above Lockport	.08	.09	.11	.04	.03	.04	.04	.04
Desplaines River at Ruby street, Joliet	3.275	2.925	2.487	2.275	2.475	2.895	2.895	2.600
Desplaines River at Brandon's bridge, Joliet	3.38	2.93	2.48	2.27	2.45	2.90	2.93	2.600
Illinois River at La Salle	.....	.475	.462	.437	.625	.750	1.125	1.575
Illinois River at Averyville	.018	.232	.280	.283	.225	.350	.510	.940
Illinois River at Pekin	.228	.185	.240	.270	.210	260	.510	.780
Illinois River at Kingston	295	.390	.385	.615	.350	.430	.720	.880
Illinois River at Beardstown	.355	.435	.364	.410	.390	.270	.550	.660
Illinois River at Grafton	.125	.125	.140	.095	.085	.70	.065	.170
Mississippi River at Grafton	.070	.070	.065	.072	.055	.045	.045	.035
Mississippi River at Alton	.070	.073	.077	.075	.055	.045	.045	.045
Mississippi River at Hartford	.063	.070	.080	.080	.055	.054	.040	.032
Missouri River at Fort Bellefontaine	.068	.070	.090	.065	.050	.063	.078	.073
Mississippi River at intake tower, Chain of Rocks	.077	.067	.085	.....	.042	.060	.068	.064
Outlet, St. Louis reservoir	.060	.055	.062	.045	.035	.035	.044	.059
Tap in city chemist's office, St. Louis	.057	.050	.063	.048	.030	.030	.045	.053

NITROGEN AS NITRITES.

Illinois and Michigan Canal at Bridgeport	0.0090	0.0200	0.0120	0.0170	0.0110	0.0140	0.0120	0.0090
Illinois and Michigan Canal at Lockport	.0000	.0000	.0000	.0012	.0013	.0030	.0020	.0017
Chicago drainage canal at Bridgeport	.0095	.0130	.0080	.0120	.0030	.0030	.0050	.0030
Chicago drainage canal at Bear Trap dam	.0102	.0102	.0110	.0070	.0130	.0120	.0090	.0100
Desplaines River above Lockport	.000	.000	.0005	.000	.0005	.0015	.0010	.0000
Desplaines River at Ruby street, Joliet	.070	.069	.071	.075	.063	.056	.031	.022
Desplaines River at Brandon's bridge, Joliet	.0700	.0691	.0710	.0750	.0630	.0561	.0312	.022[illegible]
Illinois River at La Salle	.....	.172	.156	.154	.116	.119	.064	.048
Illinois River at Averyville	.106	.154	.111	.090	.079	.076	.076	.051
Illinois River at Pekin	.105	.117	.099	.089	.091	.073	.066	.054
Illinois River at Kingston	.120	.174	.114	.114	.086	.094	.076	.058
Illinois River at Beardstown	.130	.131	.098	.102	.089	.074	.069	.063
Illinois River at Grafton	.059	.045	.053	.033	.034	.039	.036	.031
Mississippi River at Grafton	.0005	.0003	.0002	.0002	.0007	.0005	.0015	.0009
Mississippi River at Alton	.012	.006	.005	.002	.0025	.0025	.0035	.0030
Mississippi River at Hartford	.015	.010	.011	.008	.008	.012	.010	.011
Missouri River at Fort Bellefontaine	.0010	.0015	.0015	.0010	.0035	.0065	.0065	.0080
Mississippi River at intake tower, Chain of Rocks	.0020	.0010	.0015	.0020	.0035	.0050	.0060	.0030
Outlet, St. Louis reservoir	.0020	.0010	.0015	.0010	.0030	.0040	.0060	.0040
Tap in city chemist's office St. Louis	.0020	.0015	.0015	.0010	.0020	.0020	.0040	.0080

TABLE 21.—*Weekly average results of analyses of water at various points, October and November, 1901*—Continued.

NITROGEN AS NITRATES.

Sampling point.	Week ending—							
	Oct. 4.	Oct. 11.	Oct. 18.	Oct. 25.	Nov. 1.	Nov. 8.	Nov. 15.	Nov. 22.
Illinois and Michigan Canal at Bridgeport	0.09	0.15	0.08	0.07	0.07	0.20	0.09	0.15
Illinois and Michigan Canal at Lockport	.04	.11	.06	.06	.06	.15	.11	.11
Chicago drainage canal at Bridgeport	.14	.11	.07	.05	.14	10	.10	.11
Chicago drainage canal at Bear Trap dam	.06	.09	.03	.04	.07	.14	.07	.09
Desplaines River above Lockport	.06	.12	.06	.05	.05	.08	.05	.06
Desplaines River at Ruby street, Joliet	.29	.24	.25	.21	.20	.21	.15	.15
Desplaines River at Brandon's bridge, Joliet	.29	.24	.25	.22	.20	.22	.15	.16
Illinois River at La Salle	.....	2.00	1.97	1.97	1.90	1.85	1.35	1.05
Illinois River at Averyville	1.82	1.97	2.15	1.97	1.95	1.97	1.80	1.55
Illinois River at Pekin	1.71	1.93	2 03	1.93	1.80	1.89	1.70	1.59
Illinois River at Kingston	1.64	1.89	1.91	1.85	1.71	1.84	1.74	1.59
Illinois River at Beardstown	1.54	1.56	1.85	1.73	1.52	1.78	1.70	1.57
Illinois River at Grafton	1.76	1.64	1.70	1.66	1.80	1.42	1.34	1.58
Mississippi River at Grafton	.08	.12	.10	.10	.10	.12	.10	.12
Mississippi River at Alton	.40	.30	.20	.16	.13	.20	.10	.12
Mississippi River at Hartford	.56	.59	.52	.55	.58	.61	.45	.48
Missouri River at Fort Bellefontaine	.56	.50	.65	.65	.54	.61	.56	.38
Mississippi River at intake tower, Chain of Rocks	.43	.48	.47	.50	.53	.60	.53	.34
Outlet, St. Louis reservoir	.42	.43	.40	.49	.47	.45	.40	.36
Tap in city chemist's office, St. Louis	.48	.45	.37	.47	.50	.45	.43	.35

CHLORINE.

Illinois and Michigan Canal at Bridgeport	80	88	104	100	85	156	115	150
Illinois and Michigan Canal at Lockport	106	158	129	126	135	170	128	147
Chicago drainage canal at Bridgeport	12	11	10	14	10	21	18	21
Chicago drainage canal at Bear Trap dam	11	12	10	13	12	11	10	10
Desplaines River above Lockport	27	23	20	16	17	19	16	15
Desplaines River at Ruby street, Joliet	28	27	25	22	22	23	23	21
Desplaines River at Brandon's bridge, Joliet	28	28	25	21	21	22	22	21
Illinois River at La Salle	.....	22	23	20	20	20	22	20
Illinois River at Averyville	22	24	23	22	21	20	21	21
Illinois River at Pekin	22	24	24	23	22	21	22	21
Illinois River at Kingston	23	24	24	23	21	21	21	21
Illinois River at Beardstown	22	22	23	22	21	20	21	20
Illinois River at Grafton	25	23	22	22	22	21	20	20
Mississippi River at Grafton	5	6	4	4	4	4	4	4
Mississippi River at Alton	9	7	6	5	5	5	5	5
Mississippi River at Hartford	10	10	9	9	9	10	10	9
Missouri River at Fort Bellefontaine	13	16	17	20	17	24	20	18
Mississippi River at intake tower, Chain of Rocks	11	14	17	17	16	19	.....	17
Outlet, St. Louis reservoir	11	14	17	16	16	18	17	16
Tap in city chemist's office, St. Louis	13	12	15	15	17	16	20	17

In discussing the above results the witness repeated much of his testimony given in connection with the presentation of the results of analyses for the previous year. His remarks consisted of a general indictment of the drainage canal and appear in the record, pages 1255–1276. Only a few facts in addition to those already mentioned were brought out. Among them were the following:

That the sewage emptied into the old Illinois and Michigan Canal undergoes anaerobic action and when it is discharged into Desplaines

River is in an advanced state of purification, so that the aerobic action which rapidly takes place after the effluent is discharged into the river is sufficient to complete the purification after a few miles of flow in the river bed. The sewage turned into the new drainage canal, on the other hand, reaches the discharge point at Desplaines River much more quickly and the fermentative changes have hardly commenced. Therefore it was argued by the witness that the discharge from the drainage canal is carried much farther down the river before its final purification takes place than that from the Illinois and Michigan Canal; and he pointed to the alleged fact that inasmuch as the great volumes of water discharged into Desplaines River from the drainage canal markedly increase the rate of flow the danger from the sewage is much accentuated thereby.

That the water of Desplaines River above the point of entrance of Chicago drainage canal is potable.

That the nitrites at Joliet are lower than at La Salle and Peoria, demonstrating, in the opinion of the witness, that the purification is by no means complete at Peoria.

That the determinations, especially those of the nitrites, vary in samples taken from the stations along the lower reaches of the stream coincidently with variations in the upper-station samples, irrespective of the flow of the stream, demonstrating, in the opinion of the witness, the effect of Chicago sewage on the river water.

That the variations in Illinois River water at Grafton are similar to and coincident with variations at Joliet. These variations do not, however, occur in the water from Mississippi River above Grafton, and the analyses show that the water from the latter point is far superior to that from the former.

That the excessive quantities of organic matter turned into Desplaines River from the Chicago drainage canal make self-purification of the stream impossible.

That the figures, in addition to showing increased pollution caused by the opening of the drainage canal in January, demonstrate also the effect of closing the canal during the following September. The effect produced on the sanitary quality of the water at Peoria and Grafton by the opening of the canal after this closing was exactly similar to but not as pronounced as the effect caused by the original opening of the canal in January.

That the figures show that the enormous pollution caused by the flushing out of Chicago River and the drainage canal during the period from January 17 to March 16, 1900, had a marked effect on the chemical character of the water of Mississippi River at Alton and Hartford.

That the water in Mississippi River at Chain of Rocks near the Missouri shore is practically Missouri River water and is not influenced to any great extent by mixing with Mississippi River water.

That the sanitary quality of Mississippi River water as shown by the cross-section samples at Chain of Rocks is distinctly inferior to that of the Missouri.

That, although the sedimentation reservoirs connected with the St. Louis waterworks system effect a removal of 85 per cent of suspended matter and 44 per cent of bacteria, the specific ingredients denoting pollution are by no means sufficiently removed when the water reaches the consumer.

The witness then presented the results of two series of analyses of water collected from the points along Missouri and Kaw [Kansas] rivers designated on page 50. These results are contained in Table 22. The first series extended from November 13 to November 22, and the second series from November 24 to December 3. (1276–1286.)

TABLE 22.—*Results of analyses of water from Missouri and Kaw rivers at stated points, 1901.*

[Parts per million.]

Sampling point.	Total residue.		Free ammonia.		Nitrites.		Nitrates.		Chlorine.		Oxygen consumed.	
	1.	2.	1.	2.	1.	2.	1.	2.	1.	2.	1.	2.
Missouri River—												
Above Omaha	1,325	1,290	0.062	0.056	0.004	0.001	0.18	0.18	10.0	11.0	7.1	0.6
Below Omaha	1,074	1,050	.136	.126	.006	.003	.16	.14	11.5	11.5	.....	6.2
Above St. Joseph	1,225	1,135	.076	.080	.....	.006	.22	.20	12.5	16.0	9.0	7.1
Below St. Joseph	1,150	.....	.....	.....	.007	.....	.26	.....	7.0	.....	8.7	.....
Above Kansas City	1,152	1,070	.070	.116	.005	.004	.026	.24	24.2	16.0	8.1	6.2
Below Kansas City	1,290	1,100	.112	.130	.005	.004	.....	.24	18.0	23.0	8.5	6.7
Kaw River at Argentine	687	650	.062	.036	.004	.000	.100	.04	89.8	109.0	7.8	5.9
Missouri River—												
Above Jefferson City	1,295	1,055	.094	.136	.005	.008	.360	.28	20.0	23.0	9.6	6.7
Below Jefferson City	1,315	1,005	.090	.136	.006	.007	.300	.26	21.0	24.0	7.4	6.6
Above Hermann	1,740	950	.090	.106	.005	.005	.360	.28	9.0	19.0	9.0	6.5
Below Hermann	1,155	170	.090	.126	.005	.004	.360	.26	18.5	.....	5.5	6.4
Above St. Charles	1,101	950	.083	.246	.004	.005	.560	.26	18.5	23.0	9.1	6.5
Below St. Charles	1,072	940	.046	.112	.004	.006	.620	.24	19.0	23.0	9.5	6.6

The only interpretation which the witness could make of the data contained in the above table was as follows: The chemical analyses show that the Missouri River water as analyzed from Omaha down to St. Louis has a character of considerable stability. The results are fairly uniform along the route, with the exception that the high chlorines coming from Kaw River increase somewhat the amount of chlorine in the Missouri between Kansas City and St. Louis. (1287.)

The witness then discussed the fifth period of investigation, beginning December 1, 1901, and continuing to July 1, 1902. Daily samples were collected from Illinois River above Grafton until December 18, 1901, and from Mississippi River a few miles above Grafton until December 14. With the exception of these samples taken above Grafton from the two rivers no samples were collected during this period above Chain of Rocks in Mississippi River. Three cross section samples were taken at this point, as in previous periods of examination; a fourth was taken from the outlet of the sedimentation reservoir; and

a fifth from the tap in the city chemist's office. The general results of these investigations were that free ammonia and nitrites frequently rose to very high proportions in the samples from the Illinois shore. Such increases were always found to be the result of similar increases in the water of Illinois River above Grafton. A notable instance was during the second and third weeks of December, 1901, when an enormous rise in free ammonia occurred at Grafton, followed by a similar rise at Chain of Rocks, near the Illinois shore, and at the intake tower. This persisted during the early part of 1902. While the figures for Missouri River during this period were higher than usual for this stream, the samples collected at the intake showed considerably more pollution and the only inference to be drawn is that the excess of organic matter came from the Illinois side of the river. A similar instance occurred during the latter part of March, 1902. Throughout this whole investigation, ending July 1, 1902, and also the sixth period, beginning October 1, 1902, and ending January 1, 1903, the same relations were apparent. An increase in free ammonia and nitrites, which the witness accepted as indicative of sewage pollution along the Illinois shore, was always reflected in samples taken at the intake tower, at the outlet of the sedimentation basins, and finally in the water taken from the tap at the city chemist's office in St. Louis. It was the contention of the witness, in summing up the evidence presented by the chemical data gathered in the various periods, that the discharge of sewage into Desplaines River from the Chicago drainage canal is felt throughout Illinois River and down the Mississippi. The variations in the character of the water in the canal at Lockport are followed by similar variations at Peoria and these by similar ones at Grafton, the waves progressing onward even to the water taps of consumers in St. Louis. (1289–1307.)

CROSS-EXAMINATION.

The cross-examiner sought to show that the witness was not justified in selecting records of the lowest flow of Illinois River as a basis for his determination of the degree of dilution of Chicago sewage, contending that the mean stages of water would serve as a fair basis. To this the witness replied that he did so to calculate the lowest possible amount of dilution, although he admitted that such a condition was uncommon and nonrepresentative and that the mean stage of water could readily be calculated. He stated that he had sought for the lowest stages in the report of Lyman E. Cooley for 1890 and in those of Jacob A. Harman in various State board of health publications up to 1899, the avowed purpose being to show the worst possible pollution recorded on the charts presented in evidence. (1380–1382.)

The cross-examiner then sought to show that the figures given by the witness concerning the minimum flow of the upper section of the

Illinois drainage basin (1163–1166) at 600 cubic feet per second were too low, inasmuch as by his own statement the lowest recorded flow of Desplaines River was 256 cubic feet per minute, of Kankakee River 25,200 feet per minute, of Fox River 31,339 feet per minute, and of the Illinois and Michigan Canal at La Salle 37,900 feet per minute, the combined flow of which would represent a far greater amount of water than that accepted by the witness as a basis for his calculations of sewage dilution. The witness was unable to reply to this presentation, but fell back on the reports of Messrs. Cooley and Harman, which he quoted in his testimony. (1382–1386.)

The cross-examiner sought to show that the calculation made by the witness with reference to the proportion of sewage per capita at Peoria discharged in Illinois River (1212–1213) was unfair, inasmuch as Peoria is a great manufacturing center, containing distilleries, glucose works, etc., from which a disproportionate amount of organic matter is discharged into the stream, and therefore the assumption of a sewage discharge equivalent to the consumption of water was unwarranted and the basis of calculation should be raised. This was denied by the witness, who contended that the sewage conditions were representative of the majority of other cities. (1402–1405.)

The cross-examiner then took up the statement made by the witness (1213) that if the water of Illinois River came down to Peoria in a potable condition the polluting effect of Peoria sewage on the stream would be removed after running a distance of 25 to 50 miles below the city, and, presenting a supposititious case based on the specified premises, asked the witness to confirm or deny his former statement. Doctor Teichmann refused to make a direct reply, but qualified his statement made in direct testimony by asserting that chemical evidences of the pollution would be removed in that distance. His final reply to the question was as follows: "I said chemically; yes. I didn't say that at the time, but it was understood, and if I had been asked the question I would have said so at that time, that a chemical examination of the samples of water taken at a point below Peoria, and taking into consideration the general conditions of the river, I would say that that sewage disappears from the channel—that is, the chemical result would not show its presence." (1405–1410.)

The cross-examiner drew from the witness the following information: The number of wells in St. Louis in 1899 was from 3,500 to 4,000 and the number of drain-water cisterns used was about 3,000, making in all about 7,000 private water supplies to be used in the city. In 1900 there were 1,160 cases of typhoid reported. Three-fourths of the patients had used water from the city supply only, while the remainder admitted that they drank well water, but frequently would use the city supply in addition. (1436–1437.)

The cross-examiner endeavored to establish the allegation that the apparent increase in the number of typhoid cases in St. Louis was not due to greater incidence of the disease, but to more faithful reporting to the health department on the part of the practicing physicians in the city. He procured an admission from the witness that in 1900 a special letter was sent out to all physicians in the city calling attention to the fact that the law required them, under penalty, to report all cases of typhoid fever occurring in their practice and that for the seven years previous no special effort had been made to obtain compliance with this law. The witness stated that there had, nevertheless, always been general discussion in connection with the potability of the water supply, and warnings had frequently been issued by the health department against the use of the city water. (1439–1442.)

The witness then admitted that during the five years previous to 1900 the St. Louis water was not potable and required boiling or filtration to make it safe. He asserted, however, that it had become worse after the opening of the canal, and stated his belief that the pollution of the St. Louis supply previous to the opening of the canal was derived from Illinois River and that from a chemical standpoint the water from Missouri River had been, and was at the time of the testimony, in a potable condition. (1446–1448.)

On being questioned with reference to the distance which a stream must flow in order to purify itself, the witness stated that it could not be given offhand, but would require careful consideration of the local conditions, the volume of water, its character, the character of the sewage discharged, etc. He admitted that he did not know whether the sewage of St. Paul and Minneapolis was purified by flowing in Mississippi River from these two cities to St. Louis, and confessed the same lack of information concerning the sewage from McGregor, Prairie du Chien, Dubuque, Clinton, Quincy, Burlington, Keokuk, Rock Island, Moline, and Davenport. (1460–1464.)

The witness then modified his former statement concerning the potability of the Mississippi River water above the mouth of Illinois River, and stated that the water is not potable except during the summer months, when the purification processes are greatly accelerated. (1465–1467.)

The cross-examiner continued along this line for the apparent purpose of determining how the witness reconciled his statement concerning the potability of the Mississippi River water above Grafton, which receives the sewage of the above-named cities, with his opinion concerning the unpotability of the Illinois River water above Grafton. The contention of the cross-examiner was that if the witness had determined that the Mississippi water above Grafton was potable then the irresistible conclusion would be that sewage from the above-named cities must have been purified by the time it reached Grafton, and

such being the case the theory that polluted water becomes purified by running a certain distance must be correct.

The witness refused to make a direct reply, basing his refusal on his ignorance of the conditions on the drainage area without a knowledge of which he could not be expected to give an opinion. For the same reason he refused to give a direct reply to the question whether or not there were any conceivable conditions on the Mississippi drainage area above Grafton which would change his opinion of the potability of the water, it being assumed that his chemical data remained unchanged. Whatever the conditions above might be, he would draw only one conclusion from his data—namely, that the water was potable during the summer months. In short, he based his conclusion solely on chemical data. Shortly afterwards, in response to similar questions, he gave an opinion diametrically opposite to that expressed in the preceding paragraph, viz: "Practically throughout the year it is permissible as a good drinking water." He added that if he were placed in charge of the water supply of Grafton he would advise the use of raw water from Mississippi River above the city. Being further pressed, he admitted that there were some authorities who would disagree with him on the matter, and then asserted that he supported the views of this very class of authorities. The witness then stated that he would render an opinion concerning the potability of the water from chemical evidence, but would supplement it in a measure by bacteriological evidence. He then professed ignorance of any instances in which a water appeared to be unpolluted from chemical evidence but polluted from bacteriological evidence. He stated that if it should exist the water must be considered unpotable. (1467–1479.)

The witness then testified as follows:

> I am testifying to the facts as I found them at the mouth of the Illinois River. What the conditions are hundreds of miles above the mouth of the Illinois on the Mississippi I am not considering. I only ascertained the character of the Mississippi River water 3 and 5 miles above the mouth of the Illinois. "Is it good or bad?" And I find it potable, and I have so expressed it. What it might have been miles and miles above the mouth of the Illinois is immaterial, to my mind, in considering the questions involved in the investigation that I conducted these years. (1482.)

The attention of the witness was called to the fact that Doctor Ravold had declared the water of the Mississippi above Grafton unfit for domestic purposes, and after much circumlocution he stated that he differed with Doctor Ravold and held to his opinion. (1485–1490.)

The cross-examination is continued in the record to page 1697. Although many different points were taken up, no important new facts were enunciated. The greater part of the cross-examination consisted of questions apparently designed to test the qualifications of the witness as an expert on the interpretation of water analyses and the general subject of stream pollution, and it would seem to the impartial reader that the credibility of the witness suffered.

EDWARD H. KEISER.

DIRECT EXAMINATION.

Edward H. Keiser, a witness called in behalf of the complainant, in qualifying as an expert, made the following statements: Since 1899 he had been professor of chemistry in Washington University, St. Louis; for fourteen years previous he had occupied the same position in Bryn Mawr College, Pennsylvania; for eighteen months previous to that was instructor in chemistry in Johns Hopkins University, Baltimore. He was graduated from Swarthmore College, Pennsylvania, in 1880, with the degree of bachelor of science, and in 1881 took the degree of master of science; in 1884 received the degree of doctor of philosophy at Johns Hopkins University. In the summer of 1884 he studied at Freiburg, Saxony; in 1887 at Göttingen, Germany; and in 1894 at Heidelberg. He had given his entire professional life to chemistry and had been called on during his career to analyze many samples of water. (968–971.)

The witness stated that he had commenced his work for the city of St. Louis January 24, 1900, and continued the analysis of samples collected daily until October 11, following. A second series of analyses was conducted extending from October 1 to November 30, 1901 The following determinations were made in the analyses carried on by Professor Keiser: Total solids, free ammonia, albuminoid ammonia total ammonia, oxygen consumed, nitrites, nitrates, and chlorine For the first five determinations mentioned the water was used in an unfiltered state; the other three were made with filtered water. The methods used in making these determinations were described and the witness stated that they were, in general, those recommended by the American Association for the Advancement of Science. (974–980.)

Samples from the following points were analyzed in the series of 1900: Reservoir of St. Louis water-supply system at Chain of Rocks along the cross section defined by Mississippi River intake tower Illinois shore, and Missouri shore; Missouri River at Fort Bellefontaine; Mississippi River at Hartford, above Alton, and above the mouth of Illinois River; Illinois River 3 miles above Grafton and miles above Peoria; and Desplaines River at Joliet and Lockport (981.)

The witness stated that of the determinations made he regarded the nitrites and free ammonia as of chief importance, for the reason that—

> The presence of measurable quantities of nitrites in drinking water is often regarded as a sure sign of contamination, and a chemist finding a measurable quantity of nitrites in water would condemn that water as unsafe for drinking purposes; and so free ammonia likewise is of great importance for the reason that the first product produced by bacteria in decomposing sewage is ammonia. We always find a quantity of free ammonia in sewage; so the chemist lays special stress on these two constituents namely, nitrites and free ammonia. (982.)

The witness then introduced data concerning the character of the water in the reservoir at Chain of Rocks, reciting in his testimony the weekly and monthly averages of the daily determinations made. He mentioned only the determinations of albuminoid ammonia, free ammonia, nitrites, and nitrates, and it does not appear from the record that he presented tables or gave any other data. The results given are recorded in Table 23. (985–1007.)

TABLE 23.—*Weekly and monthly averages of daily analyses of water from reservoir St. Louis waterworks.*

[Parts per million.]

Date.	Albuminoid ammonia.		Free ammonia.		Nitrites.		Nitrates.	
	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.
1900.								
January 24-31	0.214	0.214	0.1112	0.1112	0.0044	0.0044	0.50	0.50
February 1-7	.199		.2265		.0074		.52	
February 8-14	.285	.271	.2345	.2098	.0080	.0133	.49	.59
February 15-21	.259		.1689		.0140		.57	
February 22-28	.344		.2094		.0240		.78	
March 1-7	.233		.1357		.0100		.61	
March 8-14	.325	.410	.1643	.1890	.0080	.0107	.91	.77
March 15-21	.582		.1980		.0120		.89	
March 22-31	.501		.2848		.0130		.67	
April 1-7	.264		.2690		.0140		.51	
April 8-14	.387	.313	.2234	.1664	.0170	.0180	.67	.56
April 15-21	.248		.1030		.0260		.53	
April 22-30	.352		.0703		.0140		.54	
May 1-7	.279		.0417		.0097		.51	
May 8-14	.285	.261	.0254	.0377	.0046	.0055	.38	.39
May 15-21	.224		.0345		.0049		.32	
May 22-31	.257		.0491		.0031		.35	
June 1-7	.155		.0234		.0040		.39	
June 8-14	.172	.182	.0066	.0130	.0039	.0032	.37	.41
June 15-21	.161		.0100		.0027		.43	
June 22-30	.240		.0120		.0020		.43	
July 1-7	.219		.0117		.0017		.51	
July 8-14	.192	.234	.0228	.0199	.0013	.0017	.49	.46
July 15-21	.249		.0265		.0021		.34	
July 22-31	.275		.0186		.0017		.51	
August 1-7	.304		.0320		.0004		.48	
August 8-14	.233	.257	.0220	.0276	.0018	.0021	.27	.35
August 15-21	.202		.0223		.0035		.22	
August 22-31	.289		.0343		.0025		.42	
September 1-7	.276		.0208		.0015		.39	
September 8-14	.238	.237	.0348	.0250	.0011	.0013	.36	.37
September 15-21	.225		.0263		.0016		.36	
September 22-30	.210		.0283		.0010		.38	
October 1-10	.335	.335	.0316	.0316	.0021	.0021	.53	.53
1901.								
October 1-7	.885		.1290		.0037		.60	
October 8-14	.677		.0510		.0029		.29	
October 15-21	.523	.673	.046	.074	.0050	.0059	.21	.38
October 22-28	.727		.....		.0048		.43	
October 28-November 4	.553		.071		.0131		.38	
November 5-11	.493		.070		.0131		.27	
November 12-18	.794	.559	.086	.074	.0143	.0130	.25	.23
November 19-25	.536		.072		.0130		.12	
November 25-30	.420		.071		.0116		.12	

In discussing the results set forth in the above table, Professor Keiser stated that early in February, 1900, the quantity of nitrites and free ammonia in the reservoir water began to increase very materially, and the water became highly polluted. This was also noted in the case of the other determinations. Beginning with the first part of the month of May, there was a gradual decrease in these constituents, and during the summer months—indeed, up to the end of the

period of investigation—the proportion thereof remained low. The results for October and November, 1901, showed considerable increase over those of the previous year. These results, in the opinion of the witness, indicated that an enormous amount of polluting matter was coming down Mississippi River and that the water could not be classed as potable, owing to the large amount of decomposing organic matter in it. (1008–1009.)

The witness then presented data on the free ammonia, nitrites, and nitrates in daily samples of Mississippi water at Chain of Rocks, taken from points near the Missouri and Illinois shores. The results are set forth in Table 24. (1013–1031.)

TABLE 24.—*Weekly and monthly averages of analyses of daily samples of water from Mississippi River at Chain of Rocks.*

[Parts per million.]

Date.	Free ammonia.				Nitrites.				Nitrates.			
	Missouri shore.		Illinois shore.		Missouri shore.		Illinois shore.		Missouri shore.		Illinois shore.	
	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.
1900.												
January 24-31	0.1208	0.1208	0.4920	0.4920	0.0070	0.0070	0.0130	0.0130	0.565	0.565	1.040	1.040
February 1-7	.2200		.4670		.0065		.0214		.457		.765	
February 8-14	.1800	.1673	.....	.4180	.0183	.0144	.0000	.0187	.457	.485	.....	.790
February 15-21	.1431		.4820		.0123		.0211		.542		.882	
February 22-28	.1200		.3050		.0200		.0136		.....		.....	
March 1-7	.1048		.3000		.0140		.0123		.688		1.205	
March 8-14	.1582	.1457	.2851	.2981	.0128	.0168	.0080	.0164	1.343	.935	.822	1.004
March 15-21	.1731		.3020		.0183		.0254		.954		1.011	
March 22-31	.1468		.3060		.0223		.0200		.754		.980	
April 1-7	.0828		.2930		.0325		.0365		.577		.977	
April 8-14	.0525	.0609	.2152	.1770	.0118	.0168	.0305	.0308	.462	.478	1.022	.936
April 15-21	.0582		.1241		.0080		.0288		.434		.897	
April 22-31	.0503		.0790		.0148		.0274		.497		.851	
May 1-7	.0445		.0571		.0057		.0175		.594		.600	
May 8-14	.0474	.0614	.0503	.0566	.0028	.0035	.0134	.0154	.451	.455	.331	.435
May 15-21	.0668		.0506		.0028		.0148		.371		.394	
May 22-31	.0871		.0685		.0023		.0178		.405		.497	
June 1-7	.0365		.0351		.0028		.0050		.325		.422	
June 8-14	.0277	.0416	.0162	.0267	.0026	.0026	.0032	.0050	.285	.364	.388	.435
June 15-21	.0374		.0214		.0028		.0035		.371		.434	
June 22-30	.0648		.0342		.0024		.0084		.474		.494	
July 1-7	.0560		.0240		.0015		.0041		.423		.508	
July 8-14	.0231	.0504	.0237	.0291	.0017	.0014	.0043	.0041	.423	.483	.514	.581
July 15-21	.0517		.0300		.0010		.0043		.434		.514	
July 22-31	.0708		.0388		.0014		.0037		.651		.788	
August 1-7	.0388		.0428		.0001		.0037		.491		.514	
August 8-14	.0174	.0322	.0260	.0304	.0015	.0012	.0077	.0063	.251	.345	.234	.419
August 15-21	.0202		.0157		.0014		.0102		.314		.304	
August 22-31	.0525		.0371		.0017		.0038		.325		.622	
September 1-7	.0368		.0271		.0016		.0070		.268		.485	
September 8-14	.0265	.0454	.0394	.0448	.0003	.0008	.0071	.0068	.320	.358	.505	.433
September 15-21	.0628		.0506		.0004		.0067		.365		.428	
September 22-30	.0557		.0768		.0011		.0067		.480		.313	
October 1-10	.0508	.0508	.0448	.0448	.0011	.0011	.0064	.0064	.617	.617	.388	.388
1901.												
October 1-7	.0805		.0869		.0024		.0110		.428		.485	
October 8-14	.0502		.0571		.0027		.0124		.428		.291	
October 15-21	.0449	.0584	.0706	.0732	.0058	.0048	.0144	.0132	.240	.375	.269	.327
October 22-28	.0449		.0557		.0048		.0160		.377		.331	
October 29-November 4	.0717		.0957		.0082		.0123		.400		.360	
November 5-11	.0634		.0714		.0124		.0167		.234		.497	
November 12-18	.0894	.0780	.0720	.0706	.0141	.0014	.0177	.0162	.257	.246	.257	.326
November 19-25	.0810		.0489		.0096		.0171		.260		.291	
November 26-30	.0844		.0648		.0128		.0170		.184		.223	

The witness stated in discussing the above table that the investigation was made in this way for the purpose of determining whether the water at the intake was of "homogeneous character" and whether the water on both sides of the river was of the same chemical constitution. A marked difference was found at times, as shown in the table. The witness pointed out that soon after the beginning of the investigation nitrites were found to be twice as great in proportion on the Illinois side as on the Missouri side, and attributed this to the fact that in February there was a rise in Illinois River coincident with the opening of the Chicago drainage canal; during the same time, however, Mississippi River was at low stage. The witness found that in general, during the analytical period, the water on the Illinois side of the river was from four to five times more polluted than that on the Missouri side. He concluded further, from the fact that the amount of nitrites in the reservoir was greater than that in Mississippi River along the Missouri shore and less than that along the Illinois shore, that there must have been a mixture of the two waters at the intake. He added that all the determinations made confirmed this interpretation. He then compared the character of the water from Missouri River opposite Fort Bellefontaine with that from Mississippi River at Chain of Rocks near the Missouri shore and declared them to be the same. He further stated that the water at Chain of Rocks near the Illinois shore was at all times Mississippi water and that the waters from the two rivers became mixed at the intake. This conclusion was reached from a consideration of the amounts of chlorine, total solids, and free and albuminoid ammonia taken at the three points at Chain of Rocks. In every case the samples from the intake represent a mean between those from the two shores. (1013–1032.)

The witness then discussed a formula by which the proportion of Mississippi and Missouri rivers waters entering the intake at Chain of Rocks might be determined. (1032–1034.) This formula may be expressed in simple equations, as follows:

$$x + y = 1$$
$$ax + by = c$$

in which

x = Proportion of Missouri River water entering intake.

y = Proportion of Mississippi River water entering intake.

a = Amount of chosen constituents in water at Missouri shore, Chain of Rocks.

b = Amount of chosen constituents in water at Illinois shore, Chain of Rocks.

c = Same in mixed water entering intake.

Taking as an example the week ending August 21, 1900, with the nitrite determination as a basis, the witness gave a practical demonstration of the use of this formula. The values of a, b, and c for the week mentioned are 0.0014, 0.0102, and 0.0035. Substituting these values in the above equation, we have—

$$0.0014x + 0.0102y = 0.0035.$$

Since in the first equation

$$x + y = 1,$$

the values may be reduced to

$$0.0014x + 0.0102\ (1 - x) = 0.0035,$$

whence

$$x = \tfrac{3}{4}\ \text{(nearly)}$$
$$y = \tfrac{1}{4}\ \text{(nearly)}.$$

The above computation showed, in the opinion of the witness, that during the week mentioned three-fourths of the water delivered to St. Louis was from Missouri River and one-fourth from Mississippi River.

It should be especially noted at this point that Professor Kedzie based the greater part of his interpretations on the nitrite determinations, occasionally considering the ammonia. Continuing with his testimony, he stated that there was always more or less Mississippi River water in the reservoir at Chain of Rocks. Although there might be one or, perhaps, two days at a time during which the water would be largely from the Missouri, yet the mixture in the reservoir would always contain a certain amount of Mississippi water. In the opinion of the witness Mississippi River is a badly polluted stream below a point a short distance above the mouth of Illinois River. Above this point the water is in much better condition. He also characterized Missouri River as a fairly good stream from a sanitary standpoint. (1034–1035.)

The witness then entered on a comparison of the nitrites in the water of Mississippi River at Chain of Rocks, Illinois shore, at Hartford, and at Alton, and stated that the determinations showed in general that nitrites were higher at Hartford than at Chain of Rocks, and again higher at Alton than at Hartford, though they were very much lower in Mississippi River above the confluence of Illinois River. The results of these determinations are set forth in Table 25. (1035–1037.)

TABLE 25.—*Weekly and monthly averages of nitrite determinations in daily samples of water from Mississippi River at Chain of Rocks (Illinois shore), Hartford, and Alton.*

[Parts per million.]

Date.	Chain of Rocks.		Hartford.		Alton.	
	Weekly.	Monthly.	Weekly.	Monthly.	Weekly.	Monthly.
1900.						
January 24-31	0.0130	0.0130	0.0183	0.0183	0.0225	0.0225
February 1-7	.0214	.0187	.0220	.0199	.0263	.0253
February 8-14	.....		.0151		.0190	
February 15-21	.0211		.0180		.0225	
February 22-28	.0136		.0248		.0334	
March 1-7	.0123	.0164	.0234	.0173	.0365	.0248
March 8-14	.0080		.0128		.0225	
March 15-21	.0254		.0140		.0211	
March 22-31	.0200		.0191		.0191	
April 1-7	.0365	.0308	.0240	.0358	.0205	.0378
April 8-14	.0305		.0345		.0394	
April 15-21	.0288		.0417		.0428	
April 22-30	.0274		.0431		.0485	
May 1-7	.0157	.0154	.0213	.0269	.0223	.0289
May 8-14	.0134		.0285		.0268	
May 15-21	.0148		.0340		.0388	
May 22-31	.0178		.0240		.0277	
June 1-7	.0050	.0050	.0080	.0099	.0075	.0104
June 8-14	.0032		.0047		.0048	
June 15-21	.0035		.0047		.0053	
June 22-30	.0084		.0225		.0243	
July 1-7	.0041	.0041	.0114	.0121	.0153	.0159
July 8-14	.0043		.0105		.0163	
July 15-21	.0043		.0123		.0177	
July 22-31	.0037		.0143		.0144	
August 1-7	.0037	.0063	.0053	.0095	.0071	.0104
August 8-14	.0077		.0080		.0100	
August 15-21	.0102		.0173		.0180	
August 22-31	.0038		.0074		.0064	
September 1-7	.0070	.0068	.0100	.0097	.0111	.0115
September 8-14	.0071		.0084		.0103	
September 15-21	.0067		.0084		.0114	
September 22-30	.0067		.0120		.0134	
October 1-10	.0064	.0064	.0101	.0101	.0124	.0124
1901.						
October 1-7	.0110	.0132	.0235	.0173	.0160	.0151
October 8-14	.0124		.0184		.0121	
October 15-21	.0144		.0150		.0180	
October 22-28	.0160		.0163		.0190	
October 29-November 4	.0123		.0137		.0102	
November 5-11	.0167	.0171	.0191	.0183	.0103	.0096
November 12-18	.0177		.0190		.0124	
November 19-25	.0171		.0167		.0072	
November 26-30	.0170		.0186		.0088	

In reply to a question concerning the effect of the sewage of Alton the witness stated that the chemical data proved that it has no apparent effect on the river, because the dilution is so great that the amount of sewage entering there does not perceptibly increase the amount of organic matter. Continuing, the witness stated that in Illinois River the nitrites are considerably higher than in the Mississippi, but far lower in the Mississippi above Grafton than they are in the same stream at Alton, Hartford, or Chain of Rocks, indicating that Mississippi River above Grafton is in a purer condition than it is below. He further stated that chemical analyses show that the pollution of the Mississippi comes from Illinois River, and that if it were not for that pollution the water of the river at Chain of Rocks along the Illinois shore would be very similar in character to that along the Missouri shore with respect to free ammonia and nitrites. Missouri

River water, however, contains more chlorine than that of the Mississippi because of the fact that large amounts of salt are emptied into the river from Kansas. He finally stated, without qualification, that were it not for the flow of the polluted waters of Illinois River the Mississippi at Chain of Rocks would afford a good drinking water on both sides of the channel. (1041–1043.)

A chart was then introduced (Complainant's Exhibit No. 22) showing graphically the variation in the quantities of nitrites found in Illinois River above Grafton and above Peoria. It was the contention of Professor Keiser that this chart showed that the water in Illinois River above Grafton was inferior to that in Mississippi River at Alton, and that as Illinois River was ascended the conditions became worse, and his conclusions from these facts were as follows: Although before the opening of the drainage canal Illinois River contained sewage matter, there was greater oxidation in the region above and immediately below Peoria and in fact all along the river, the movement of the water was slower in the river, and while the water was impure above Peoria a smaller quantity of nitrites was found, showing that oxidation had proceeded further than it did subsequent to the opening of the canal; in other words, by the turning in of so great a quantity of water into the Illinois system the "region of bacterial action and the conversion of the nitrogenous organic matter into nitrites was moved much farther down Illinois River and into Mississippi River below the mouth of the Illinois." The witness further stated that inasmuch as the analyses made during October and November, 1901, showed a more highly polluted condition than those made during 1900 the conditions were growing worse rather than improving. (1043–1046.)

Data concerning the nitrites and free ammonia in Illinois River at various points were presented and are included in Table 26. (1042–1060.)

The witness then stated that the analyses indicate a decided increase in the amount of impurities since the opening of the canal. In his judgment this pollution continues down to Chain of Rocks, a portion of it finding its way to the intake tower of the waterworks and thence to the reservoir at St. Louis. As the volume of water going down Illinois River is greater now than previous to the opening of the canal there is less opportunity for sedimentation to take place. (1048–1049.)

The maximum allowable amount of free ammonia is 0.05 part per million, and when this is exceeded the water is to be regarded with suspicion. If there are measurable quantities of nitrites the water should be condemned, inasmuch as good drinking water should have no nitrites in it. (1052.)

TABLE 26. *Monthly averages of daily determinations of nitrites and free ammonia in water from Illinois River at specified points.*

[Parts per million.]

Date.	3 miles above Grafton.		Above Peoria.				At Joliet.				At Lockport.			
	Nitrites.	Free ammonia.	Nitrites.		Free ammonia.		Nitrites.		Free ammonia.		Nitrites.		Free ammonia.	
			Weekly maximum.	Monthly average.	Weekly maximum.	Monthly average.	Weekly maximum.	Monthly average.	Weekly maximum.	Monthly average.	Weekly maximum.	Monthly average.	Weekly maximum.	Monthly average.
1900.														
January 24-31	0.0300	1.498	.....	0.0248	.....	2.485	.....	.....	.....	.....	.....	.....	.....	.....
February	.0245	.946	0.0414	.0358	2.169	1.416	.....	.....	.....	.....	.....	.....	.....	.....
March	.0170	.322	.0268	.0209	1.201	.685	0.067	0.0558	3.491	2.689	0.0945	0.0643	3.095	2.437
April	.0370	.113	.0771	.0467	.455	.392	.1014	.0663	3.140	2.732	.1011	.0730	2.591	1.806
May	.0459	.1079	.1023	.0752	.361	.266	.0340	.0256	3.604	2.995	.0405	.0234	2.236	1.598
June	.0193	.0321	.1448	.1317	.319	.228	.0345	.0326	3.600	3.270	.0295	.0114	1.677	1.411
July	.0352	.0443	.2171	.1657	.401	.230	.0728	.0551	4.647	3.710	.0114	.0081	1.834	1.631
August	.0239	.0406	.1743	.1597	.172	.142	.0597	.0465	3.999	2.933	.0140	.0083	1.974	1.589
September	.0257	.0517	.2171	.1382	.672	.255	.0754	.0524	5.473	4.498	.0108	.0071	2.685	2.195
October	.0428	.0677	.....	.1857	.....	1.404	.0562	.0562	.....	3.306	.....	.0130	.....	1.555
1901.														
October	.0720	.1502	.....	.....	.....	.....	.0830	.0780	5.519	3.801	.0172	.0167	1.663	1.446
November	.....	.....	.....	.....	.....	.....	.0781	.0510	3.494	3.152	.0210	.0189	1.368	1.239

The witness gave the data presented in Table 27, with reference to the amount of chlorine in the water of Illinois and Mississippi rivers above Grafton. (1053.)

TABLE 27.—*Monthly averages of daily determinations of chlorine in water from Illinois and Mississippi rivers above Grafton, 1900.*

[Parts per million.]

Month.	Illinois River.	Mississippi River.	Month.	Illinois River.	Mississippi River.
January	14.1	5.7	June	12.6	5.1
February	13.1	6.1	July	18.0	7.7
March	7.0	4.5	August	16.5	5.2
April	6.1	4.8	September	14.8	3.3
May	10.9	4.2	October	16.9	3.9

He then gave the comparisons shown in Table 28 with reference to Illinois River above Grafton and above Peoria. (1047–1048.)

TABLE 28.—*Monthly averages of daily determinations of nitrites and free ammonia in water from Illinois River above Grafton and above Peoria.*

[Parts per million.]

	Grafton.		Peoria.	
	Nitrites.	Free ammonia.	Nitrites.	Free ammonia.
October, 1900	0.0428	0.0677	0.1857	1.40
October, 1901	.720	.1502	.1240	.30

The witness then gave the following data concerning the water from the drainage canal off Pauline street, Chicago (1060–1064):

TABLE 29.—*Determinations of free ammonia, nitrites, and chlorine in daily samples of water from the Chicago drainage canal off Pauline street.*

[Parts per million.]

Date.	Free ammonia.	Nitrites.	Chlorine.	Date.	Free ammonia.	Nitrites.	Chlorine
1901.				1901.			
October 9	0.328	0.016	22.8	November 6	0.568	0.015	10.
October 10	2.860	.040	23.0	November 7	.652	.018	16.
October 11	.676	.018	18.0	November 8	.436	.028	12.
October 12	.812	.017	12.1	November 9	.452	.015	10.
October 13	1.66	.036	20.8	November 10	.849	.015	14.
October 14		.015	21.0	November 11	.560	.013	14.
October 15	1.072	.017	19.0	November 12	5.192	.025	106.
October 16	1.500	.018	23.2	November 13	.568	.015	12.
October 17	.884	.018	19.5	November 14	.640	.015	9.
October 21	.672	.019	22.3	November 15	.468	.027	8.
October 22	.334	.027	22.5	November 16	.428	.016	11.
October 23	.884	.013	17.5	November 17	.588	.023	11.
October 24	.796	.016	18.2	November 18	.452	.015	9.
October 26	.732	.015	22.0	November 19	.560	.016	11.
October 27	1.020	.014	21.3	November 21	.716	.007	8.
October 28	1.288	.025	21.7	November 22	.564	.013	11.
October 29	.744	.016	23.8	November 23	.504	.018	11.
October 30	.700	.019	29.0	November 24	.628	.017	12.
October 31	.744	.018	24.2	November 26	.404	.017	9.
November 1	.968	.028	21.5	November 27	.968	.017	11.
November 2	.628	.016	23.0	November 28	256	.016	16.
November 3	.648	.017	13.8	November 29	1.892	.017	16.
November 4	.988	.013	13.2	November 30	2.140	.015	29.
November 5	1.068	.017	11.3				

The results were then discussed by Professor Keiser substantially as follows:

From these analytical results it is apparent that the water of Illinois River was more highly contaminated with nitrogenous organic matter at Joliet and Lockport than at Peoria. Higher values are shown for free ammonia and nitrites at Joliet than at Lockport. This is accounted for by the fact that the samples at Joliet were taken immediately under the Illinois and Michigan Canal, which passes over the river at that point. The analyses are typical of sewage; it can not be called water. Several months after the analyses began, the quantities of nitrites and free ammonia diminished both at Lockport and at Joliet. This is accounted for by the outflow of the water of the drainage canal. In other words, after the opening of the drainage canal this concentrated sewage at Lockport and Joliet was diluted. That, in part, is the result shown by the analyses. The results obtained at Peoria and points below show that this sewage from Lockport and Joliet had been washed farther down the river. There were at Grafton much higher nitrites and free ammonia after the opening of the canal than before, and that is evidence of the flushing down of the sewage matter which had accumulated at Lockport and Joliet and in the upper regions of the river. (1064-1065.)

Professor Keiser was recalled to the witness stand for the purpose of making comprehensive interpretations of the chemical data which had been offered in evidence by the witnesses on behalf of the plaintiff. He submitted the data given in Table 30 concerning the analytical results. The first and second entries in the table are the averages of 17 analyses made from May 2, 1893, to January 24, 1894, by the water department of St. Louis, and originally appeared in the message of the mayor for 1894. The third entry is the average of 21 analyses made at intervals from December 15, 1892, to April 20, 1894, in the chemical laboratory of Washington University. The fourth entry is an average of 26 analyses made by the city chemist at intervals from September 9, 1899, to January 22, 1900. The remainder of the table consists of data given in the testimony of Dr. William C. Teichmann.

TABLE 30.—*Average results of sanitary analyses of Mississippi River water at St. Louis.*

BEFORE OPENING OF DRAINAGE CANAL.

Date.	Number of samples.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Sampling point.
May 2, 1893, to January 24, 1894.	17	1.033	0.046	0.003	0.38	.....	Distributing well.
April 14, 1893, to January 24, 1894.	17	.411	.019	.002	.44	.....	Settling basin.
December 15, 1892, to April 20 1894.	21	.310	.048	.005	.38	.....	Not designated.
September 9, 1899, to January 22, 1900.	26	.522	.063	.002	.39	.....	Intake tower.

TABLE 30.—*Average results of sanitary analyses of Mississippi River water at St. Louis*—Continued.

AFTER OPENING OF DRAINAGE CANAL.

Date.	Number of samples.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Sampling point.
February, 1900	28	0.676	0.217	0.013	0.60	.....	Intake tower.
March, 1900	31	1.202	.348	.014	.80	.....	Do.
April, 1900	30	1.036	.186	.020	.60	9	Do.
May, 1900	31	1.190	.094	.011	.50	10	Do.
June, 1900	30	1.148	.070	.004	.30	11	Do.
July, 1900	31	1.350	.127	.004	.30	10	Do.
August, 1900	31	.810	.101	.005	.40	12	Do.
September, 1900	30	.818	.093	.004	.70	15	Do.
October, 1900	31	.898	.118	.006	.60	9	Do.
November, 1900	30	.705	.098	.007	.60	10	Do.
December, 1900	31	.289	.105	.011	.40	17	Do.
January, 1901	31	.396	.144	.009	.80	19	Do.
February, 1901	28	.296	.121	.007	.70	19	Do.
March, 1901	31	1.455	.310	.013	1.3	11	Do.
April, 1901	30	1.034	.191	.016	1.1	6	Do.
May, 1901	31	.506	.088	.002	.4	9	Do.
June, 1901	30	1.161	.105	.002	.5	10	Do.
AVERAGES.							
Before opening	[a] 81	0.569	0.044	0.003	0.40	.....	
After opening	[a] 515	.880	.150	.009	.6	12	

[a] Total.

In interpreting the above data the witness stated that the analyse recorded prior to the opening of the canal show that the water wa comparatively stable and not unwholesome compared with its subse quent condition. January 17, 1900, the drainage canal was opened The water must have reached St. Louis about the beginning of Febru ary and the results are clearly shown in the analytical statement mad for that month. A portion of the great increase noted in free ammoni and nitrites in February and March might have been due to the fac that in the winter months impurities are usually found to run highe than in spring and summer, but the increase during these two month was very much greater than had been observed in any previous year From the subsequent results it is apparent, according to the witness that the character of the water has permanently changed. (1697 1702.)

In reply to questions concerning the Missouri River data, the wit ness presented the average results recorded in Table 31. Contrastin the condition of the water before and after the opening of the canal he stated that the differences were slight—that no change resulted i the general character of the water—showing conclusively that th changes noted in the Mississippi River water at the Chain of Rock intake tower, could not have been due to any increase of impuritie in Missouri River. (1702-1704.)

TABLE 31.—*Average results of sanitary analyses of Missouri River water near Fort Bellefontaine.*

[Parts per million.]

BEFORE OPENING OF DRAINAGE CANAL.

Date.	Number of samples.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.
Prior to February 1, 1900	19	0.499	0.107	0.0045	0.39
AFTER OPENING OF DRAINAGE CANAL.					
February 1 to October 10, 1900	268	1.203	0.142	0.007	0.50
October 1 to November 30, 1901	61	.631	.069	.003	.55

The witness then testified concerning the results in evidence, with reference to the character of the water of Mississippi River at Hartford, 1 mile above the mouth of the Missouri, 17 analyses of the water having been made at intervals between August 3 and December 4, 1899. The average of these analyses, together with those obtained after the opening of the canal during the periods January 23 to October 10, 1900, and October 1 to November 30, 1901, will be found in Table 32. (1705.)

TABLE 32.—*Average results of sanitary analyses of Mississippi River water opposite Hartford.*

[Parts per million.]

BEFORE OPENING OF DRAINAGE CANAL.

Date.	Number of samples	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.
August 3 to December 4, 1899	17	0.622	0.107	0.004	0.5
AFTER OPENING OF DRAINAGE CANAL.					
January 23 to October 10, 1900	260	0.613	0.275	0.018	0.7
October 1 to November 30, 1901	61	.368	.062	.011	.54

In interpreting these results, the witness pointed out the fact that at Hartford, as at the intake, there had been a permanent increase in the amount of pollution in the water after the opening of the canal. (1704–1706.)

The witness then took up the analyses of samples from Mississippi River above the mouth of the Illinois and presented the average results, as shown in Table 33. (1706–1707.)

TABLE 33.—*Average results of sanitary analyses of water from Mississippi River above mouth of Illinois River.*

[Parts per million.]

BEFORE OPENING OF DRAINAGE CANAL.

Date.	Number of samples.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.
September 6, 1899, to January 17, 1900.	18	0.503	0.069	0.002	0.30	6.0
AFTER OPENING OF DRAINAGE CANAL.						
January 23 to October 10, 1900.....	264	0.587	0.138	0.008	0.46	5.0
October 1 to November 30, 1901.....	61	.348	.057	.001	.10	4.3

The witness stated that these data plainly showed that the water from Mississippi River above the mouth of the Illinois is in stable condition, and that practically no change has taken place in its composition since the opening of the canal—a fact which excludes the possibility that the change in the character of the St. Louis water is due to increased impurities in the upper Mississippi. (1706–1707.)

He then gave the results of analyses of samples of water from Illinois River 3 miles above Grafton, collected before and after the opening of the Chicago drainage canal. These results are included in Table 34. (1707–1708.)

TABLE 34.—*Average results of sanitary analyses of Illinois River water 3 miles above Grafton.*

[Parts per million.]

BEFORE OPENING OF DRAINAGE CANAL.

Date.	Number of samples.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine
September 6, 1899, to January 17, 1900.	19	0.553	0.215	0.012	0.8	25.
AFTER OPENING OF DRAINAGE CANAL.						
January 23 to October 10, 1900.....	265	0.509	0.272	0.032	0.96	13.
October 1 to November 30, 1901.....	61	.373	.110	.043	1.71	21.

The witness stated that prior to the opening of the canal th Illinois water above Grafton was badly polluted and unpotable Nevertheless, for ten months after the opening of the canal ther was an increase in free ammonia of nearly 27 per cent and in nitrite of 167 per cent. The only conclusion to be drawn from these figure is, according to the witness, that after the canal was opened ther was a much larger quantity of sewage undergoing putrefactive chang than before, and he argued that it was this sewage from Illinois Rive which had caused a permanent change in the character of the wate entering the St. Louis intake at Chain of Rocks. (1707–1708.)

The witness then presented the average results of analyses of water from Illinois River above Grafton and above Peoria; from Desplaines River at Joliet; from the Illinois and Michigan Canal and the drainage canal at Lockport, and from Lake Michigan. These results are shown in Table 35. (1708–1710.)

TABLE 35.—*Average results of analyses of water from stated points, January 23 to October 10, 1900.*

[Parts per million.]

Sampling point.	Number of analyses.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.
Illinois River 3 miles above Grafton	265	0.482	0.239	0.034	1.11	14.7
Illinois River 3 miles above Peoria	260	.284	.468	.095	1.48	19.4
Desplaines River at Joliet	219	.452	2.732	.057	.22	23.9
Illinois and Michigan Canal at Lockport	.....	.....	13.250	.009	0	150.0
Drainage canal at Lockport	219	.....	1.585	.026	.15	15.0
Lake Michigan	219	.....	.043	.005	.15	6.0

The witness pointed out that the figures in the above table show that the water becomes steadily more and more impure as Illinois River is ascended, and that the entire river is in a highly polluted condition. The water of Lake Michigan, from which the supply of the two canals is derived, is in good condition from a sanitary standpoint, and the fact that it contains so large an amount of organic matter by the time it reaches the canals is sufficient proof that this matter must be derived from the sewage of Chicago, the results of which are traceable all along the valley and down to the St. Louis intake. (1708–1710.)

The witness made and discussed a series of statements concerning the pollution or amount of organic matter in water from various points before and after the opening of the Chicago drainage canal, based on averages of analyses made at specified periods. He considered that the determinations of albuminoid and free ammonia and nitrites would constitute a sufficient index of pollution. The results are set forth in Table 36. (1073–1078.)

TABLE 36.—*Averages of analyses of water at chosen points before and after the opening of the Chicago drainage canal.*

[Parts per million.]

Sampling point.	Albuminoid ammonia.		Free ammonia.		Nitrites.	
	Before.	After.	Before.	After.	Before.	After.
Reservoir, St. Louis	0.214	0.271	0.111	0.210	0.004	0.013
Mississippi River at Alton	.200	.728	.288	.460	.212	.104
Missouri River at Fort Bellefontaine	.063	.395	.135	.148	.008	.014
Mississippi River above Grafton	.478	.565	.113	.176	.005	.005
Illinois River above Grafton	.478	.913	.113	.946	.005	.025
Illinois River above Peoria	[a] .572	[a] 2.210 [b] .627	[a] .895	[a] 3.060 [b] 1.950	[a] .141	[a] .060 [b] .030

[a] According to J. H. Long. [b] According to E. H. Keiser.

The periods of analyses included in the above table are as f

For the reservoir at St. Louis: Before opening of canal, January, 1900.
After opening of canal, February, 1900.
For Missouri River at Fort Bellefontaine: Before opening of canal, January,
After opening of canal, February,
For Mississippi River at Alton: Before opening of canal, January, 1900.
After opening of canal, February, 1900.
For Mississippi River above Grafton: Before opening of canal, January, 190
After opening of canal, February, 190
For Illinois River above Grafton: Before opening of canal, January 23–31, 1
After opening of canal, February 21–28, 1
For Illinois River above Peoria: Before opening of canal, J. H. Long's result
After opening of canal, Long's results, Fe
April, inclusive, 1900, and those of the
February to March, inclusive, 1900.

According to the witness the figures in Table 36 show unmis that there was a great increase in the pollution of Illinois Riv the opening of the canal, but no corresponding increase in the Mississippi above Grafton or of Missouri River at Fort Belle

CROSS-EXAMINATION.

The cross-examination brought out the admission from P Keiser that he had made no personal investigation of the River drainage area and that the physical conditions, except might be learned from maps, were unknown to him. He d however, that such knowledge is not necessary to an int interpretation of his results. (1080–1081.)

The cross-examiner then endeavored to show that the meth by the witness to determine the proportion of Mississippi and M river waters entering the intake at St. Louis is faulty, beca algebraic formula does not take account of the relative amo water furnished by these streams, to which the witness res that no such fallacy is involved, because the values are true i tive of the volumes of water making the mixture. If in a mix Missouri and Mississippi river waters the amount of Missour was one-third greater than the Mississippi, but the Mississip luted twice as much as the Missouri, the degree of pollution mixture chargeable to each stream would not correspond w relative volumes of the two streams, but with the relative prop of impurity. (1100–1103.)

In response to questions, the witness then gave the monthl age results of his analyses of water from Missouri River a Bellefontaine. (1104–1106.)

TABLE 37.—*Monthly averages of daily analyses of water from Missouri River at Fort Bellefontaine, 1900.*

[Parts per million.]

Month.	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.
January	0.363	0.135	0.008	0.415	23.5
February	.395	.232	.014	.592	18.6
March	1.182	.144	.023	.965	12.1
April	.775	.069	.018	.485	12.5
May	1.484	.083	.013	.484	14.5
June	1.181	.067	.003	.418	11.4
July	1.556	.055	.001	.462	11.2
August	.842	.038	.001	.435	12.8
September	1.133	.068	.002	.381	16.3
October	1.382	.055	.002	.560	11.4

The witness stated that he had made no determinations of the volume of water contributed to Illinois River by its tributaries nor had he taken this into consideration. He had regarded all the impurity found in Illinois River as coming from the drainage canal, because these impurities increased steadily as the river was ascended. If the impurities were derived from the tributaries, the amounts of albuminoid and free ammonia and nitrites would be fairly constant throughout the length of the main stream, but inasmuch as there was a constant increase all the way upstream and as at Joliet the river water was found to be merely dilute sewage, the chief cause of pollution must lie in the drainage canal. (1108–1110.)

The cross-examiner then directed the attention of Professor Keiser to that part of his testimony in which he referred to a report of Prof. J. H. Long in presenting figures to show the comparative condition of the water of Illinois River at Peoria before and after the opening of the canal. He pointed out that the witness had given for free ammonia the values 0.895 (Long) before the opening and 3.060 (Long) and 1.950 (Keiser) after the opening. (See p. 87.) The cross-examiner showed that the witness had selected Long's free ammonia determinations from samples taken at "The Narrows," above Peoria, to show the condition before the opening of the canal, and the determinations from samples taken at Wesley, below Peoria, and in the field of high contamination from Peoria sewers, to show the condition after the opening of the canal. It appears from an examination of the testimony and Long's report that three series of examinations were conducted by him at Peoria. The first extended from July 5 to November 29, 1899, the samples being taken at Peoria Narrows (above Peoria) and at Wesley (below Peoria); the second extended from March 7 to April 25, 1900, all the samples being taken at Wesley; the third extended from June 7 to October 10, 1900, the samples being taken at both points mentioned.

The witness finally admitted that he had compared the figures for Peoria Narrows for 1899 (before canal opening) with those for Wesley

for March and April, 1900 (after canal opening). In attempting to justify this comparison the witness made the following statements: First, as no analytical results appeared in Long's report with reference to the water above Peoria in the examination of March and April, 1900, and as the witness desired to procure data for a period as close as possible to the opening of the canal he had selected the Wesley figures for the stated period, believing that the effect of the Peoria sewage was negligible. Second, the analyses made by Long of water taken from Peoria Narrows, July 5 to November 29, 1899, and June 7 to October 10, 1900, would not admit of comparison by average statements, as the comparisons were stated in the witness's testimony, because the average of the determinations for 1899 included analyses made during November, while those of 1900 ended October 10. Free ammonia and nitrites increase greatly in November, and to include these determinations in the average for 1899 would result in an unfair comparison in favor of the defendants. Why, if such were the case, he did not make the comparison by eliminating the results of Long's analyses for November, 1899, and leaving only the determinations extending to October 10, the date of the closing of Long's investigation of 1900, he did not venture to explain. It is evident from the testimony that he believed it equitable to take for comparison the results of an entirely different part of the year, viz, March and April, 1900. Third, while he had quoted figures from Long's report, as above stated, he also included the results of his own analyses for 1900, and his interpretations were not affected by Long's results. Why, if such were the case, he included them in his testimony was not explained.

The cross-examiner pointed out that had he taken Long's results for Peoria Narrows in 1900 there would have appeared in the comparison a great decrease in ammonia and nitrites instead of the increase reported. The witness thereupon denied that such a comparison would be warranted for reasons above stated.

After further questions concerning the figures of the comparison made by the witness, he made the following statements:

> I wasn't aware that there was any certain degree of difference. In making this comparison I found the table on page 44 [Long's report] was the nearest one that Professor Long has published of results made after the opening of the drainage canal, and I took Peoria here as being the nearest point to that point where I had taken samples for analysis. I didn't know where it was exactly, and I didn't know whether the sewage of Peoria got into the river at Wesley. I thought it was considerably below, if anything. I did not think it was right in the town of Peoria. (1128–1129.)

The cross-examiner then called the attention of the witness to page 36 of Long's report, in which values for free ammonia, albuminoid ammonia, nitrites, and nitrates are given for samples of water taken at the Narrows, above Peoria, from July 5 to November 23, 1899, and again to page 64 of the same book, where values are given for the

same determinations from samples taken at the same point during the period from June 7 to October 9, 1900. It will be noted that these two periods are before and after the opening of the canal, respectively. The witness was then asked if in the showing for free ammonia, albuminoid ammonia, nitrites, and nitrates there was a considerable reduction in the latter period as compared with the former period. To this he replied "Yes," and in explanation of this reply made the following statement:

I wish to state that we are now comparing analyses of waters made at different seasons of the year. We are comparing analyses made in the fall of the year, from July down to the end of November, when the rivers are apt to be low, with the analyses made in the early summer, * * * when the rivers are apt to be swollen with rainfall, and therefore it is not altogether a good comparison. In my work I was not endeavoring to establish the yearly value. I was endeavoring to determine what the effect of the opening of the canal was, and for that purpose I compared [analyses made before the opening of the canal[a]] with the analyses made immediately after the opening of the canal * * * and I found my own analyses showed an increase immediately after the opening, taking analyses as near as we have them to the opening. (1131–1132.)

The cross-examiner then called the attention of the witness to that part of his testimony in which he affirmed that the waters of Missouri River at Fort Bellefontaine and of Mississippi River above the mouth of the Illinois were fairly good from a sanitary standpoint. He then recalled the statement of the witness that water containing a measurable quantity of nitrites should be regarded with suspicion. Finally, he reviewed the testimony of the witness concerning the character of the water of Missouri River at Fort Bellefontaine, in which he stated that there was an average of 0.008 and 0.014 part per million of nitrites before and after the opening of the canal, respectively, and asked him to reconcile these statements. In reply, the witness stated that only during the summer months were the nitrites low and the water potable, but during the winter the nitrites were high and the water was unfit for use in its raw state. (1132–1134.)

Other features of this cross-examination are of interest as showing the basis on which the witness interpreted sanitary analyses. In reply to various questions he made the significant statements that he did not include in the evidence presented the determinations of total solids, because they would throw very little light on the sanitary condition of the water; that he would be able to give an opinion as to the sanitary condition of the St. Louis water without a knowledge of the chlorine content, although in general to determine the potability of water this factor should be taken into consideration; that the determination of oxygen consumed is not always of importance, although at times it assists in forming an opinion about the water, especially when very little is known about the natural history; that he did not think it necessary to determine dissolved oxygen, because

[a] Phrase in brackets missing in record; inserted here to complete sentence.

it did not add information of value; that he considered the determination of albuminoid ammonia of very little value in determining the character of the waters under discussion. (1711–1717.)

It was apparent from the statement of the witness (1716) that he accepted an absolute standard of potability defined by the analysis as follows: Free ammonia should not be greater than 0.1 part per million and the nitrites should be hardly measurable. Several analyses were recited to him and he at once designated the waters good or bad according as the ingredients were below or above the standard just mentioned.

GEORGE CHANDLER WHIPPLE.

DIRECT EXAMINATION.

George Chandler Whipple, called as a witness on behalf of the complainant, in qualifying as an expert, stated that he was biologist and director of the Mount Prospect laboratory of the department of water supply, gas, and electricity of the city of New York, and that he had held that position since 1897, except that before the consolidation of New York and Brooklyn he was employed by the city of Brooklyn. He had graduated from the Massachusetts Institute of Technology in 1889 in the course of civil engineering, and immediately after graduation was employed on some water-filtration experiments under Desmond Fitzgerald, superintendent of the Boston waterworks. In the fall of the same year he was placed in charge of the newly established biological laboratory of the Boston water department, with the title of biologist, and was given supervision of all the water supplies of the city. In connection with this work he made tests of sewage and water purification plants and trips of inspection to other water supplies in the State and to the Lawrence experiment station. He made many studies on the growth of organisms in water, on the temperature of large bodies of water, and on stagnation phenomena, and assisted in designing the thermaphone, an instrument for obtaining the temperature of water at the bottom of reservoirs. In 1896 he spent four months with Prof. Albert R. Leeds in the study of the Brooklyn water, which at that time was infected with organisms, causing a bad odor. In 1897 he established the Mount Prospect laboratory for the city of Brooklyn, the scope of which was later extended to cover all the water supplies of Greater New York. In 1903 all the sanitary work of the extensive investigation on an additional water supply for the city of New York was placed in his hands. He had had considerable private practice and had carried out in that capacity a number of important investigations connected with water-supply questions. He is the author of a book entitled "The Microscopy of Drinking Water" and is engaged in a work on hygienic analysis and another on water supply. He devised

the scheme for numerically recording odors in water and also the silica standard for turbidity. He is a member of the American Society of Civil Engineers, the American Chemical Society, the American Microscopical Society, the Society of American Bacteriologists, the American Public Health Association, the Society of Chemical Industry, and the American Limnological Commission and a fellow of the Royal Microscopical Society of London. He was at the time of the testimony secretary of the laboratory section of the American Public Health Association, and secretary of the committee on standard methods of water analyses of that section. (1903–1908.)

The witness testified that during the months of October and November, 1901, he had made microscopical examinations of 136 samples of water collected from various stations on Lake Michigan, the drainage canal, Illinois River and its tributaries, and Mississippi and Missouri rivers, with the object of determining the number and character of the microscopic organisms present. In certain of these samples he also made determinations of the turbidity and the color. Mr. Whipple described microscopic organisms as "those minute forms of life which are too small to be readily identified without the use of a microscope, but which are large enough so that they do not need to be studied by artificial cultures as we study bacteria." The witness stated it as his opinion that in the transit from the point of collection to the laboratory at Brooklyn certain of the forms present might die out, others might increase somewhat, and still others would remain practically unchanged in numbers. (1909–1911.)

The witness then put in evidence fifteen sheets showing the results of his examinations. (See Table 9, p. 29.) After describing in some detail the organisms found in the various waters he directed special attention to the diatoms. He stated that owing to the character of the diatom skeleton, which is of silica and practically indestructible, this organism was more likely than other microscopic organisms to be identified after the trip from Lake Michigan through the drainage canal and Desplaines and Illinois rivers to the St. Louis intake. (1911–1922.)

The following testimony is especially important:

Q. Are you able or not to say from your examinations and your knowledge upon this subject whether any particular species of these diatoms or micro-organisms came from Lake Michigan or not?

A. There were certain diatoms found during my examinations which appeared to be characteristic of Lake Michigan and Lake Michigan alone—I would like to change that—Lake Michigan and nowhere else excepting the streams below to which the water from Lake Michigan has access.

Q. Can you say whether or not any of the micro-organisms which were peculiar to Lake Michigan were found in the Mississippi River at the intake? And, if so, state which ones they were and how they got there.

A. There was an organism which I will describe as *Synedra pulchella* variety *subprolongata* which was found at the intake of the waterworks at the Chain of Rocks, and which was found also in the water of Lake Michigan, but which was not found in the water of the Missouri River or the water of the upper Mississippi River, or in any of the tributaries of the Illinois River unless we consider the Chicago drainage canal as being a tributary. (1924.)

The summary of the counts of this class of organisms appears in Table 38. (1925.)

TABLE 38.—*Average results of examinations for microscopic organisms in samples taken at designated points.*

[Number per cubic centimeters.]

Source of samples.	Synedra.	Tabellaria.	Melosira.	Cyclotella.	Asterionella.	Stephanodiscus.
Lake Michigan	577	236	13	38	25	8
Drainage canal at Lockport	270	236	13	30	22	2
Desplaines River at Lockport	2	2	1	264	113	9
All other tributaries of Illinois River	17	3	2	709	13	1
Illinois River above Peoria	126	62	8	48	10	3
Illinois River at Beardstown	95	19	0	784	31	0
Illinois River at Grafton	90	46	8	4,468	41	3
Mississippi River at Grafton	1	0	2,400	1,372	569	307
Mississippi River at Alton	19	16	1,741	2,534	124	174
Missouri River at Fort Bellefontaine	5	0	22	16	0	6
Mississippi River at Chain of Rocks, Illinois shore	51	21	1,380	1,957	396	192
Intake tower, Chain of Rocks	16	0	403	443	40	93
Settling basin, St. Louis	0	12	0	256	68	10

Referring to this table, witness stated his belief that the 16 *Synedra* found at the St. Louis intake came not from the Mississippi nor the Missouri, but from Illinois River, and that since there were 577 *Synedra* in Lake Michigan and all the tributaries of the Illinois together except Desplaines River gave only 17 *Synedra*, the *Synedra* at the intake came from Lake Michigan by the drainage canal and Desplaines River. Similarly he concluded that the *Tabellaria* found in the settling basin came mainly from the lake rather than from any other source; that the *Melosira* found at the intake came not from Illinois River nor from Lake Michigan, but from Mississippi River above Grafton; that the *Cyclotella* came chiefly from Mississippi and Illinois rivers and only to a slight extent from the lake; that the *Asterionella* came in the main from the Mississippi; and that the *Stephanodiscus* came mainly from the Mississippi above Grafton. (1926–1929.)

Mr. Whipple then introduced five charts (complainant's Exhibit No. 47, pls. 1–5) showing diagrammatically the figures given in Table 38, and discussed the variations noted. (1930–1934.)

Two diagrams were then introduced, one showing the results of an examination of samples from twelve points in a cross section of Mississippi River above Alton and the other the results of a similar examination of eleven samples on a cross section of the Mississippi about 1 mile above Chain of Rocks. Besides the numbers of the microscopic organisms in these samples the witness determined also the color and

the turbidity. He made a calculation from the relative numbers of *Melosira*, *Cyclotella*, *Asterionella*, and *Stephanodiscus* present in the Missouri River water at Fort Bellefontaine, the Mississippi River water at Alton, and the water at the intake of the St. Louis waterworks to determine the relative amounts of Missouri River water and Mississippi River water (including Illinois River water) entering the intake, estimating the proportions as 68 per cent of Missouri water and 32 per cent of Mississippi water. (1934–1941.)

Mr. Whipple described Mississippi River in respect to the direction of its banks and the curves of the river between the mouth of the Missouri and Chain of Rocks. He stated that the curves were of such a nature that they would tend to allow or increase or would be favorable to the mixture of the waters which came down Mississippi and Missouri rivers. In his opinion, if the figures introduced in evidence concerning the total solids in Missouri and Mississippi river waters (Table 20, p. 63) are reliable, then the calculations based on them to show the percentages of the waters of the two rivers entering the intake are also reliable. He stated that the total solids were the most accurate analytical determinations to use in such a calculation, because the two streams in question differ most widely in that respect. Chlorine, alkalinity, and color may also be used for the same purpose. (1978–1989.)

If only the cities on the drainage area of Mississippi River above St. Louis having 25,000 population or more are considered, the addition of Chicago doubles the population contributing sewage to the river, while if all communities having a population of 4,000 or more are considered the addition of Chicago increases the total contributing population by 63 per cent. The limit of 4,000 is the one commonly used by sanitarians in considering the population contributing pollution to a given drainage area, and it is assumed that the small amount of pollution from towns not included in the estimate is balanced by an equal amount from inhabitants of the communities included who are not connected with sewerage systems. (1989–1991.)

From complainant's Exhibit No. 1, already in evidence, the witness had calculated certain average analytical figures, as follows: Daily samples from October 30 to November 29, 1901, collected at five points in a cross section of Mississippi River at Alton, gave the average figures shown in Table 39 for nitrites and chlorine. Station A was at the Missouri shore, station E at the Illinois shore, and the other stations were intermediate. (1992.)

TABLE 39.—*Averages of nitrites and chlorine in Mississippi River at Alto November 29, 1901.*

[Parts per million.]

Station.	Nitrites.	Chlorine.	Station.	N
A	0.002	5.2	D	
B	.005	6.8	E	
C	.009	8.7		

Similar samples for the same period from five points in tion of Mississippi River at Hartford gave the average re in Table 40. (1993.)

TABLE 40.—*Averages of nitrites and chlorine in Mississippi River at Hart to November 29, 9101.*

[Parts per million.]

Station.	Nitrites.	Chlorine.	Station.	N
A	0.006	6.8	D	
B	.006	7.1	E	
C	.008	8.0		

From these figures, together with similar averages from River at Grafton and Illinois River at Grafton (the latte of averages not being offered in evidence), the witness ca percentage of Illinois River water at the five points in ea tion, as shown in Table 41. (1993–1994.)

TABLE 41.—*Percentage of Illinois River water in Mississippi River at Alt ford, October 30 to November 29, 1901.*

Station.	Alton.	Hartford.	Station.	A
A	7.8	17.17	D	
B	7.7	19.5	E	
C	29.3	25.0		

The longevity of the typhoid bacillus in natural waters by the witness to be several months, though the numbers ually decrease. On the assumption that the Chicago sew the St. Louis intake in ten and one-half days, he stated as that if typhoid organisms were present in the Chicago se of them would survive the passage to the intake, and that flood, when the journey from the lake to St. Louis is ma days, a greater proportion of such germs would survive. epidemics at Detroit and Lawrence, in both of which the had persisted in the water for a period of over ten and on On the assumption of an increased typhoid death rate i

since the opening of the drainage canal and of a normal amount of the disease on the drainage basin of Mississippi River above the city, and the further assumption that the source of the St. Louis water supply had remained unchanged during the time considered, the witness stated that, in his opinion, the increase in the typhoid death rate in St. Louis was most probably due to the discharge of the Chicago sewage into Mississippi River. (1996–2002.)

On the assumption that large numbers of *Bacillus prodigiosus* were placed in the waters of the drainage canal at Lemont and that the same organism was found in the city water of St. Louis after the lapse of a proper time, the witness believed that the organisms at St. Louis originated in those placed in the canal. He stated that the longevity of *B. typhosus* and *B. prodigiosus* was, so far as his experience enabled him to judge, about the same. He further believed that if, since the opening of the drainage canal, a larger amount of the Chicago sewage has reached Mississippi River than formerly, the water of the river has become less valuable as a source of domestic supply. (2002–2009.)

CROSS-EXAMINATION.

On cross-examination Mr. Whipple stated that the best way to determine the presence of sewage in water is to actually find out whether or not sewage enters the water. In the absence of this information analytical results will supply the information in some cases only. If the water is grossly polluted, analyses will show the presence of the contaminating matter, but if it is only slightly polluted the presence of such matter can not be determined in this way. There are no qualities of water which, taken alone, would enable the witness to determine possible pollution, but among the qualities which he would naturally consider in forming an opinion would be the amount of organic matter as shown by the determination of nitrogen as albuminoid ammonia, free ammonia, nitrites, and nitrates, together with the amount of chlorine, the hardness, the total and suspended solids, and the color; also the number of bacteria in the water and the presence of particular species of bacteria, such as *Bacillus coli communis*. The witness stated that he would further take into consideration the possible presence of certain microscopic organisms commonly associated with sewage. It is not always necessary to make all the determinations above noted. With respect to certain of the determinations, the witness stated that there is no such substance as "albuminoid ammonia," this being merely a form of expression used in describing the amount of organic matter present. "Free ammonia" is used in a similar manner, and it is taken to mean that the water contains ammonium compounds that on boiling are broken up so that the

ammonia is driven off. Neither of the two terms is the name of a substance actually existing in the water, but they stand for substances. (2051–2061.)

With reference to the significance of the presence of *Bacillus coli communis*, the witness said that he could not state definitely that it indicates sewage origin. It is believed by many scientists that this organism may be found in waters where pollution is remote. It is a common inhabitant of the human intestine and is present in large numbers in ordinary sewage. As it is abundant in waters known to be polluted and occurs only in small numbers or is entirely absent in waters presumably not polluted, most bacteriologists agree that the test for the presence of this organism is highly important in determining the presence of pollution. If the organism is constantly or very often present in a water it is probably an indication of sewage contamination. In the opinion of the witness, however, it is not an absolute test, but a valuable one, to be interpreted in connection with the remainder of the analysis. Even though this bacillus might be found in the intestines of fish, it would not, in his judgment, materially influence the interpretation to be made from the results of the *coli* test, because it had been his observation that fishes' intestines do not ordinarily contain this bacillus, and if it is present there it is probably derived from the water in which the fish is living. (2075–2077.)

Referring to micro-organisms, the witness stated that he did not know of any that absolutely demonstrate the presence of sewage, but there are certain organisms which are so often associated with sewage that in a very general way they do serve as an index of its presence. However, it could not be asserted that a stream was sewage polluted merely because these organisms were found there. (2078.)

The witness could not state definitely the number of typhoid germs discharged by one patient, but as a general statement it was true that the number is enormous. Under certain conditions this number would be sufficient to create an epidemic if they were turned into water used for a city supply, but many factors would be involved among which are the original vitality of the organisms, the rate at which they might die out in water, the relation of the number of organisms to the amount of water that they enter, the amount of sedimentation that might occur between the time at which they infected the water, and the time at which they entered the city intake, the influence of certain microscopic organisms, and the possible influence of sunlight. He knew of no scientist who had actually demonstrated how long the bacillus of typhoid will live in the sewage-contaminated water of a stream, but some men have arrived at certain conclusions by way of laboratory experiments. According to the results of such experiments, the time may be stated as varying from some weeks to some months. (2080–2082.)

The witness stated that he knew of some investigators who had claimed to have discovered the typhoid germ in river water, but was unable to state whether the claim was substantiated. In the earlier days of bacteriology, when species were not so carefully studied as they are to-day, certain results were obtained and published by bacteriologists that would hardly be credited in the present state of the science. (2082.)

The effect of dilution was then discussed by the witness, who stated that if a certain number of typhoid bacilli were put into different amounts of water and thoroughly mixed, the larger quantity of water would contain the fewer bacteria per unit volume. This statement, however, assumed a uniform distribution of the bacilli throughout the water, which he did not regard as a condition that would be likely to exist. Usually when bacilli are discharged into water, many of them are clustered together and held in that condition by some force or substance, while on the other hand some of them are widely distributed throughout the water; but the conditions are not such as would allow the dangerous qualities of typhoid-polluted water with different degrees of dilution to be fairly compared. (2083–2084.)

Referring to the speed of current necessary to permit sedimentation, the witness stated that if the velocity is reduced to about half a foot per second, sedimentation of suspended matter of a certain character might occur. If the suspended matter were coarser it would settle in a current of greater velocity, but he could imagine such matter so fine that it would not settle even if the velocity were only a quarter of a foot per second. The knowledge of the subject had not reached a point where any strict rule could be given. The whole matter of sedimentation depends on the character of the suspended matter, the temperature, and other conditions, as well as the velocity of flow. Experiments have been made on the subject, but not in sufficient number to warrant the formulation of a precise statement. (2088–2089.)

It was the opinion of the witness, from what he knew of the existing conditions on the drainage area of Missouri River and from the fact that there are salt deposits in the drainage area of Kaw River, that the amount of chlorine found in Missouri River at Fort Bellefontaine can not be used as an index of pollution, although part of it may have been derived from sewage pollution, because the effect of the chlorine from the salt deposits would interfere with interpretations relating to sewage pollution alone. (2090–2091.)

With reference to the rôle played by microscopic organisms in the purification of waters, the witness stated that there was practically no knowledge on the subject. These organisms might perhaps exert some influence on bacteria, but the information was not very definite. (2101.)

The cross-examiner then referred to the testimony of the witness in which he expressed the opinion that the *Synedra pulchella* variety *subprolongata* found in the water of Illinois and Mississippi rivers was probably derived from Lake Michigan, and endeavored to draw from him a statement as to his reasons for this opinion. The witness admitted that this organism could exist in the ponds and lakes along the lower reaches of Illinois River. The following question and answer are given substantially as they appear in the record:

Q. Assume that the relative amount of water now discharged from the drainage canal into Illinois River is greater than that naturally flowing in that river, and further assume that the number of *Synedra* and *Tabellaria* per cubic centimeter in the waters of Lake Michigan and in the waters of the Illinois River lakes and tributary streams are exactly equal; that in all physical respects the organisms from both sources have equal vitality when they start from their habitat on a journey to the St. Louis intake; that the ones from Lake Michigan have to pass through the drainage canal; and finally, that these microscopic organisms are found in the water at the St. Louis intake. Eliminating all other considerations than those above mentioned, to which source would you prefer to attribute them?

A. If we have a certain volume of water contributed by the tributaries of Illinois River and the assumed lakes which contain a certain number of these organisms, and if we have a greater volume of water through the Chicago drainage canal which contains per cubic centimeter an equal number of these organisms, and assuming a thorough mixing of the waters from both sources, it would be my judgment that these organisms would come from both sources, but that more of them would come from the water which was greatest in volume, provided the two waters contain an equal number per cubic centimeter. The fact that the organisms from Lake Michigan had traveled through 24 miles of sewage would be of no practical significance. (2104–2106.)

The witness stated that if bacilli naturally inhabiting running water should be removed, developed by special culture, put in bottles of sterilized water, and hung out in the sun, the determination of their longevity under such conditions would not enable us to tell how long they would live in natural water or give any definite information on that point, although it might guide in an opinion as to how long they might live. (2111–2112.)

With reference to the longevity of *Bacillus prodigiosus*, it was the opinion of the witness that if a stream were infected with a large culture the numbers of the bacteria would probably decrease, but just how rapidly he was not prepared to say. If a 40-gallon barrel full of *Bacillus prodigiosus* culture were dumped into Illinois River at or near its mouth in August, 1900, and if in November of the following year 107 barrels full of the same culture were discharged into the drainage canal near Lockport, and after this latter discharge a colony of these bacilli were found at the intake of the St. Louis waterworks and another at some point in the distribution system of the city, the witness would naturally assume it to be more reasonable to consider that these colonies were derived from the second discharge, if they came from either, because during the interval between August, 1900, and November, 1901, all of the water in Illinois and Mississippi

rivers between the point where the first dose was added and the intake of the St. Louis waterworks would have passed downstream, and many, if not all, of the bacilli would have died in that time. Therefore it was not likely that the *B. prodigiosus* found in St. Louis in 1901 were derived from the culture discharged into Illinois River in August, 1900. (2112–2114.)

The importance to be attached to the numerical results of a single bacteriological examination of water was discussed by the witness, who stated that if the number of bacteria was extremely low it might indicate a comparatively good sanitary condition; if extremely high it might indicate the reverse, but if the number was intermediate no conclusions could be drawn from that alone. In order to obtain the most accurate result the bacteriological examination of a sample should be begun immediately after its collection, though the character of the water would to a considerable extent determine this point. A water containing comparatively little food for bacteria might be allowed to stand longer before the bacteriological examination than a water rich in organic matter, and the result of the examination would not be seriously affected. (2120–2122.)

The witness expressed the opinion that investigators had not ascertained by any experiments the probable duration of pathogenic germs, such as the typhoid-fever bacillus, in running water. In general, experiments such as had been made under laboratory conditions would be less favorable to such bacteria than natural conditions. Of course, it must be considered that circumstances alter cases, but in very general terms he believed this statement to be true. He was referred by the cross-examiner to page 294 of a work entitled "Micro-organisms in water," by Percy and G. C. Frankland, in which the results of experiments made by Krans with unsterilized waters were cited. On this page the statement was made that the typhoid bacilli had disappeared or were no longer demonstrable when the water bacteria became active. The witness stated that he was of the opinion that no such assertion could be warranted, because the identification of the typhoid bacillus in the presence of common water bacteria is extremely difficult and in most instances impossible. The details of the report were then enumerated, namely, that the water, taken from the Munich supply, contained on the first day 57,960 typhoid bacilli; on the second day, 50,400; on the third day, 15,680; on the fifth day, 9,000, and on the seventh day none, while there were no ordinary water bacteria on the first, second, and third days, 80 on the fifth day, 288,000 on the seventh day, 400,000 on the ninth day, and 970,000 on the twentieth day. In regard to these results, the witness stated that it was no wonder that the investigator did not find the typhoid bacilli in the samples at the end of the seventh, ninth, or tenth days, because he believed it a bacteriological impossibility to

demonstrate the presence of typhoid germs under such circumstances, and he would question whether the results obtained would actually stand the test of present-day methods. The subject has been very carefully considered, and the poverty of the results shows the difficulties encountered. (2131–2133.)

The cross-examiner then cited two series of results given in the work above mentioned. The first referred to the river Spree. The water of this river passes through Berlin and receives the city sewage. A few miles below Berlin the river widens into a fairly quiescent body of water known as Havre Lake. The results show that the water leaving Havre Lake had become purified from the effects of Berlin sewage to such an extent that its condition, as shown by the analytical results, was practically the same as above Berlin. The second case was that of the river Limmat, flowing out of Lake Zurich. The number of micro-organisms in the water as it leaves the lake varies from 100 to 200 per cubic centimeter. This number is increased enormously by the inflow of sewage from the city of Zurich; but at a point about 6 miles below, the bacterial condition approaches that of the water as it leaves the lake. The cross-examiner then asked whether, in view of these two instances, on the assumption that the conditions are truly stated, it was not highly probable that the water of Illinois River above Peoria, a distance of over 100 miles from Chicago, would have attained a bacteriological condition similar to that which it had before it received the Chicago sewage. The witness stated that the results cited would not be of any material value in estimating what the bacteriological conditions would be at Peoria, but that the experiments made seemed to be in line with what is generally known in regard to the decrease in the total number of bacteria in streams below points at which pollution is introduced. It is quite conceivable that the conditions in Illinois River between the Chicago drainage canal and Peoria are such that the total number of bacteria at the latter point might be as low or even lower than in the water of Lake Michigan; but in taking this into consideration the character of the bacteria at Peoria must be considered. The probability is that pathogenic germs would decrease in transit, as well as the water bacteria; but whether they would decrease in exactly the same proportion the witness was not able to state. It is conceivable that there might be a greater decrease in the pathogenic germs than in the ordinary water bacteria, but that would depend on the character of the water bacteria and the conditions of the water. It should be remembered that even the water bacteria are not at all times multiplying. They are sometimes dying, and certain forms of the water bacteria might die at even a greater rate than the typhoid bacilli under such conditions. If we neglect all other considerations, such as sedimentation, etc., and consider only the fact that typhoid

bacilli do not multiply in water, while water bacteria will multiply under the conditions presumed, it is not probable that the typhoid bacilli would remain alive in water as long as the water bacilli; but in practice, it would not do to neglect all other considerations in studying a problem of this character. (2133–2138.)

The witness then stated that the reason why cities having a population of 4,000 or over were often considered in estimates as having a polluting influence on the water of a river, while those of a smaller population were not so considered, was that this limit furnishes, on the whole, a better means of comparing the effect of human life on different drainage areas than to take the total population. The reason for this was that throughout the country, communities of 4,000 population or over are more commonly provided with a public water supply than those having less than 4,000. The witness admitted that this is an arbitrary distinction, but claimed that, taken broadly all over the country, it is a fair one. It is true that rural pollution may be washed from barnyards and feeding pens by rains into a river, but such added pollution has no real effect, because there is at the same time an enormous dilution, so that the result may not be different from that which would occur under normal conditions with a constant pollution of the stream by a sewer, for example. (2145–2147.)

ALLEN HAZEN.

DIRECT EXAMINATION.

Allen Hazen was called as a witness in behalf of the complainant. In qualifying as an expert on water supplies, Mr. Hazen stated that he was educated at the public schools of Hartford, Vt., at the New Hampshire State College, the Thayer School of Civil Engineering, Hanover, N. H., and at the Massachusetts Institute of Technology, and later, for one term, at the technical school in Dresden, Germany. He further testified that he had made a special study of the chemistry of water supplies; that for a number of years he was in direct charge of the experiment station of the Massachusetts State board of health at Lawrence, with the title of chemist; that he had twice visited Europe and studied the water supplies and sewerage systems of most of the large cities there; that he was in charge of the sewage-disposal plants and the inspection of drinking waters at the world's fair at Chicago at 1893; and that he was at one time a member of the firm of Noyes & Hazen, of Boston, who gave special attention to water supply and sewerage problems. He advised the city of Albany, N. Y., on the subject of its water supply and later superintended the construction of sand filters there; was then building a filter for the city of Ithaca, N. Y., and had been engaged in similar work for Harrisburg, Pittsburg, Chester, and Lancaster, Pa.; West Superior, Wis.; Watertown and Yonkers, N. Y.; Providence, R. I.; Washington, D. C.;

Trenton, N. J.; Toledo, Ohio; Grand Rapids, Mich., and Millbury, Mass.; and for a few years acted as consulting engineer for the Ohio State board of health. In 1891 the witness visited Chicago and examined its waterworks and sewerage systems, becoming generally familiar with the conditions existing at the time. In 1892 he published jointly with Professor Sedgwick a paper on the water supply and typhoid fever in Chicago. In 1893, with Doctor Reynolds, health commissioner of Chicago, he wrote a joint paper on the water supply of Chicago, which was read before the American Public Health Association. The following year he wrote a report on the drinking water used at Jackson Park during the world's fair. He was a member of the commission appointed in 1901, consisting besides himself of Messrs. Williams and Wisner, to report on an improved water supply for St. Louis. He then examined thoroughly the water system of the city and the whole drainage area. (2789–2798.)

The witness stated that he believed that the quality of the water at the St. Louis intake was seriously damaged by the sewage of Chicago and based this view on the facts that the amount of sewage entering the watercourses above the intake has been nearly doubled by this discharge; that the distance between Chicago and St. Louis is very considerably less than the average distance of the other points of pollution from the St. Louis intake; that the mixing of the waters in the channel of the Mississippi is such that the amount of sewage received at the intake is a large percentage of what it would be if the mixing were complete; and that the time of passage from the point of pollution to the intake is not sufficient to allow the complete destruction of the injurious and polluting matters discharged. In view of these facts the witness believed that the discharge of the sewage of Chicago into Mississippi River by way of the drainage canal Desplaines River, and Illinois River "seriously injures the quality of the water." (2799–2802.)

CROSS-EXAMINATION.

The witness gave evidence of thorough familiarity with the water-supply system of the city of St. Louis and the conditions of the Illinois, Mississippi, and Missouri river basins above the intake, with reference to their population, the pollution of the rivers, and the degree of mixing which takes place, such familiarity arising from his work as commissioner in 1901. In connection with this work he had examined the waterworks plants at Kansas City, St. Joseph, and Omaha on Missouri River, and taken into consideration the discharge of sewage into the stream from these cities. He finally stated that he did not consider Mississippi River at Chain of Rocks a fit source of supply nor would the water be safe for drinking even though the pollution brought in by the Illinois were eliminated. The cities

lying along Missouri and Mississippi rivers above St. Louis discharge sufficient polluting material to render the use of the water without previous purification dangerous. (2809–2813).

In explanation of the comparative statements concerning the safety of water which he had made, the witness said that some waters are so polluted that they cause the death of more than one person per thousand per annum from typhoid fever; in fact, sometimes as many as four or five persons; such water is extremely bad, and probably as bad as is used anywhere in the United States. Waters that are less polluted than this produce smaller amounts of sickness and death. It is difficult to draw the line absolutely and it may be a question whether even the best waters are absolutely free from suspicion of causing typhoid. But when a water causes so little sickness that it can not be traced and measured, it is classed as a good water, so that the various degrees of acceptability are merely relative, depending on the effect of the water on the persons using it habitually as a beverage; no sharp line of demarkation can be drawn. (2814.)

The witness stated that the diversion of Chicago sewage from the lake and into the drainage canal would undoubtedly greatly improve the Chicago water supply, but that he was of the opinion that it would not render it absolutely safe, because the shipping is a source of considerable pollution. The matter discharged from vessels entering and leaving Chicago is undoubtedly a menace to the purity of the water supply, but just how important a menace the witness was not prepared to say. (2817–2819.)

The dilution of Chicago sewage by the large influx of Lake Michigan water, according to the witness, would not mitigate the danger to St. Louis. Such dilution would have some effect on the sewage, but its effect on the specific germs of disease would be doubtful, and these germs, after all, are the real sources of danger. In discussing the various factors in the self-purification of streams, the witness stated that sedimentation is a mere transference of some of the polluting matters from the moving water to the bottom of the stream. He would not call that purification, because such sewage matter is liable to be taken up again and transported. If the water alone is considered it is purification, but in a broad view of the whole subject it is not. (2824–2825.)

The witness stated that no definite length of time could be set during which it would be necessary for such sewage to lie upon the bottom of a stream in order to become noninjurious, but that in the Millbury case he was confronted by the proposition, backed up by eminent experts, that the trouble was due to sewage mud which had been deposited several years previously. (2827.)

With reference to the function of analytical work in showing the potability of water, the witness stated that chemical analyses never

show infection; they can only show pollution, from which infection can sometimes be inferred. The bacteriological examination may possibly show the presence of infectious matter, but the difficulty of finding it, even when it is known to be present, is so great that it is very seldom found. (2837.)

The witness was then questioned concerning the relative importance of cases and of deaths as an index of the amount of typhoid fever present, replying that if, as stated, the number of deaths from typhoid fever at St. Louis were 168 in 1900, 198 in 1901, and 222 in 1902, and the total number of cases reported were for the same years 1,213, 1,101, and 1,112, respectively, he would give greater weight to the deaths than to the cases in considering the amount of typhoid in the city. He believed that under the conditions prevailing in American cities the number of deaths from typhoid is a more accurate measure of the typhoid than the number of cases, because the deaths are more accurately and carefully reported. The above record, if true, would indicate that the disease was occurring with greater severity, and this might reasonably be called an increase in the typhoid condition. (2838–2841.)

In answer to questions as to the amount of mixing which occurs at the junction of the Missouri and the Mississippi, Mr. Hazen stated that from analyses which he had seen it was his belief that the water received at the St. Louis intake contained 30 per cent of Mississippi River water. He could not state how much of this water came from the Illinois, but was of the opinion that the mixing of the Illinois and the Mississippi waters was, owing to the nature of the channel, fairly complete. (2844–2847.)

WILLIAM THOMPSON SEDGWICK.

DIRECT EXAMINATION.

William Thompson Sedgwick, called as a witness on behalf of the complainant, qualified as an expert by stating that he graduated at Sheffield Scientific School, Yale University, in 1877; studied for the greater part of two years at Yale Medical School; taught physiological chemistry at Yale for one year, and then became fellow, assistant, and associate at Johns Hopkins University; since 1883 had been assistant professor, associate professor, and professor in the Massachusetts Institute of Technology; received the degree of doctor of philosophy at Johns Hopkins in 1881; served as biologist to the State board of health of Massachusetts from 1888 to 1896; is a member of the American Academy of Arts and Sciences, Massachusetts Association of Boards of Health, New England Waterworks Association, Society of American Bacteriologists, American Society of Naturalists, American Public Health Association, and of the advisory board of

the hygienic laboratory of the United States Public Health and Marine-Hospital Service; past president of the American Society of Naturalists and of the Society of American Bacteriologists; has been employed by various cities and towns as an expert in water supply and sewage disposal, especially by Burlington, Vt., Pittsburg, Pa., and Lowell, Mass.; is the author of a text-book on general biology and of a treatise on the principles of sanitary science and the public health; has made numerous reports and investigations of epidemics of typhoid fever for the State board of health of Massachusetts and a report on typhoid fever in Pittsburg in 1898; has published numerous papers on water supply, water purification, and sewage purification; and in 1892, in collaboration with Allen Hazen, published a paper on typhoid fever in Chicago. (2184–2185.)

The witness then made certain general statements concerning the Chicago water supply and methods of sewage disposal, and stated that he was familiar with conditions prevailing in the Illinois River basin along the Mississippi above St. Louis and in general throughout the drainage basin of Missouri River. He defined ordinary pollution as a condition in which the water contains organic matter, or even filth, from whatever source and in whatever degree of putrefaction, without the presence of the specific germs of any disease; the term infectious pollution refers to water containing germs of disease, without reference to the amount of putrescible organic matter or any physical condition whatever. A water polluted with organic wastes, however bad it may appear, is not, in general, dangerous to public health if it does not contain the specific germs of a water-borne disease; on the other hand, a water that is perfectly clear and acceptable from a physical standpoint may be dangerous to public health by reason of the presence of disease germs. (2187–2190.)

Mere dilution does not destroy or eliminate infectious pollution. Under dilution alone, the sewage turned into Illinois River from the sanitary district of Chicago would not be rendered safe and pure by the time it reached Peoria. In this whole matter of self-purification of streams the ideas of to-day are very different from those of twenty or thirty years ago. Running water under some conditions might purify itself from infectious germs, but those conditions would be so unusual as to be virtually theoretical. Experts have abandoned the old belief that running water readily purifies itself. Acting on that belief, which was the result of the best knowledge available twenty or thirty years ago, numerous cities and towns of the United States installed waterworks with intakes in streams into which sewage had been poured at points above. That was the best art of the time, and engineers, chemists, and sanitarians agreed about it. The city of Pittsburg, for example, introduced a water supply from Allegheny River with the confident belief that such sewage as might find its way

into that river at points above would be effectually removed before the water came to the citizens. That belief has been found to be erroneous. Pittsburg suffers to-day with typhoid fever perhaps more than any other city of the United States. The cities on the lakes—Niagara Falls, Buffalo, Cleveland, Detroit, Chicago, Milwaukee, Duluth—take water supplies exposed to contamination by sewage, and are to-day, one after another, considering at any rate the possibility of abandoning such supplies, because of the failure of the self-purification of sewage. Nevertheless, there is a large measure of self-purification of streams. The subject is complex and difficult, and the tendency of opinion has been to increase distrust in the efficiency of self-purification of water or sewage. (2191–2192.)

In reply to specific questions concerning the effect of the discharge of Chicago sewage from the drainage canal, the witness stated that such discharge at once throws suspicion on the character of the water in Illinois River and undoubtedly affects the entire water-supply value of the stream and that of the Mississippi at the St. Louis waterworks, rendering the water dangerous for drinking purposes and more liable to carry germs of typhoid fever. (2193–2195.)

The addition to the flow of Illinois River of the water from the Chicago drainage canal, equivalent to about five-sixths of the minimum flow of said river, will quicken the flow in the channel and thereby hinder effective sedimentation by shortening the time required for infectious germs to pass through the river, and, by interfering with their detention, will aggravate the danger of their arrival at the mouth of the river. The witness laid especial stress on the statement that any factor which results in quickening the flow of the stream is of grave importance. The time, more than the distance, is the basis of self-purification in streams. Other things being equal, the rate of sedimentation is quicker in a turbid water than in a clear water. An addition of clear water, like that from Lake Michigan, to the water of Illinois River will serve to retard sedimentation. Therefore these two factors—namely, the quickening of stream flow by the addition of a large quantity of water and the partial clarification of the river due to the fact that this water added from Lake Michigan is clear—undoubtedly have the effect of increasing typhoid fever in St. Louis. (2195–2196.)

The witness stated that the matter deposited in the bed of a running stream may lie there for some time or may be swept out by an increase in the velocity of the stream. In case it is allowed to remain for some time, it may be more or less modified by chemical and bacterial action. If it is swept from the bottom of the stream by an increase in the velocity, it may be redeposited at lower points or pass into some other body of water. In regard to the longevity of typhoid as a general proposition in connection with sewage-polluted water, to speak broadly,

recent observations have indicated a greater longevity than was formerly supposed. Practical experience has shown that in a sewage-polluted stream typhoid germs may live in gradually diminishing numbers for weeks or months, or even years. Continuing, the witness stated that even if the number of colon bacilli, as shown by actual tests, was no higher subsequent to the opening of the canal than previously, it does not indicate that the water is not more dangerous for drinking purposes. The mere fact that a vast additional population is contributing sewage to Illinois River must always constitute an added menace to the health of the persons using the waters of the river at its mouth or below. Bacteriological examinations are, in the opinion of the witness, not absolute guides as to the sanitary condition of water, because they obviously can not be made at every moment or at all times or at all seasons or hours of the day, and therefore there might be intervals between times of sampling when infectious materials would flow by and thus escape analysis, but nevertheless would pass on and do harm to the people using the water below. (2197–2198.)

If typhoid-fever germs coming from Chicago sewage are deposited in large numbers in the lakes and slack-water portions of Illinois River above Peoria, in event of flood conditions the water leaving these lakes might contain more infectious and dangerous pollution than the sewage entering Desplaines River at the Bear Trap dam, because a large amount of typhoid fever in Chicago might result in the storage of vast numbers of these germs in the slack-water basins, and a sudden flood would sweep out this accumulation, so that sometimes more typhoid-fever germs would be flowing in Illinois River than in the drainage canal itself. The witness then mentioned the case of the city of Detroit, where the removal of deposits of sewage matter had resulted in a typhoid-fever epidemic. The dredging of Black River at Port Huron caused the carriage of detached sediment down St. Clair River, through St. Clair Lake, and into the intake of the Detroit waterworks. (2198–2199.)

Continuing, the witness expressed the opinion that the water of Illinois River as it enters the Mississippi can not be used with safety for drinking purposes. Assuming that the only pollution of the Illinois is contributed to it by the Chicago sanitary district, he was emphatically of the opinion that the effects of time interval, dilution, and sedimentation between Chicago and Grafton would not be sufficient to render the water as it enters the Mississippi at all times free from disease-producing elements. In support of this contention he cited the Lowell epidemic, in which the large body of water in Merrimac River was contaminated by a small amount of water in Stony Brook, and compared the conditions as to volume and size of the rivers under consideration. (2199-2201.)

The witness stated that for fifteen years prior to 1900 the typhoid death rate of St. Louis was not in general greater than that of many cities provided with purer water supplies. During the period following the removal of the water intake from Bissells Point to Chain of Rocks, the typhoid death rate in the city had been remarkably good—lower in fact, than the rate for the same period in Boston, which has a good water supply and a reasonably normal incidence of the disease. Since January 1, 1900, there has been a marked annual increase in the typhoid rate of St. Louis, which has been higher than at any time in its own history since 1885, and very much higher than the Boston rate, with which it previously compared favorably. The increase in the number of deaths from typhoid fever in St. Louis between January 1, 1900, and the date of the testimony, over the number of deaths from the same disease in the previous fifteen years, excluding one year (1892) in which there was a great epidemic due to the causes specified in the testimony of Doctor Ravold, has been about 26 per cent, while the increase since January 1, 1900, in annual mortality from typhoid over that for the preceding five years, was 73 per cent. Before 1900 the typhoid death rates of St. Louis and of Boston were below those of most cities having polluted water supplies. New York has the lowest death rate from typhoid fever; Boston and St. Louis ran very closely together until January 1, 1900, since which time Boston has gone lower and St. Louis increased; Philadelphia shows a much higher death rate than Boston and St. Louis, while Chicago has the worst record of all. (2202-2203.)

Professor Sedgwick referred to the experiment made with 107 barrels of *Bacillus prodigiosus* culture, which were emptied into the Chicago drainage canal at Lemont, the germs, as reported, having been identified in the water entering the St. Louis intake at Chain of Rocks, and stated that this interesting and valuable experiment seems to show that typhoid fever or Asiatic cholera germs might pass from the drainage canal and finally enter the water supply of St. Louis by way of Illinois and Mississippi rivers. (2204-2205.)

On being questioned with reference to instances in which typhoid-fever epidemics have been conveyed by surface waters, the witness gave a brief summary of several prominent cases.

A celebrated and important epidemic occurred at Plymouth, Pa., in 1885. On the drainage area supplying the town four storage reservoirs had been built, and on the bank of the stream which supplied the uppermost of these reservoirs a case of typhoid fever appeared in the early spring of 1885. The reservoirs had all been drawn very low to supply the demands of a continued season of cold weather, and on the arrival of the spring thaw 1,200 cases of typhoid fever broke out in this little town of 8,000 inhabitants. These were traced—correctly, it is believed by sanitarians—to the occurrence of one case of typhoid

fever on the bank of the uppermost reservoir, followed during the thaw by the washing in of the dejecta of that patient and, in the low state of the reservoirs, the rapid transmission of the germs to the people of the town. (2205-2206.)

In 1890 there was an epidemic at Lowell, Mass., followed very soon after by a worse one at Lawrence, 9 miles below on the Merrimac. These were traced to infection which began on Stony Brook, and of course the Lawrence sickness was caused largely by the typhoid-fever germs in the sewage of Lowell, the larger city above it. (2206.)

Two years after, in 1892, the witness investigated a very interesting epidemic at the mouth of the same river, in Newburyport. The people of the city supposed that they were drinking spring water, but the superintendent of the waterworks had surreptitiously connected the mains with the Merrimac, and for two or three months the people were getting, as he himself admitted, Merrimac River water. This was particularly instructive because for the first two months, say, of this time there was no typhoid in Newburyport. On going up the river the witness found the reason to be that although they had been drinking simple filth—good straight sewage—it was apparently uninfected. Unluckily, however, a little epidemic broke out in Lowell, the result of which was perfectly obvious in Lawrence, although the water had to travel 9 miles and pass through a storage reservoir where it had been detained for at least a week. This infected water reached Newburyport, at a distance of 20 or 30 miles, and it was one of the saddest cases ever investigated, because the people supposed that they were drinking spring water, while they were in fact drinking infected sewage. (2206-2207.)

The rivers pollution commission of Great Britain, in a report published in 1874, states that there is no river in the United Kingdom long enough to purify itself from any sewage admitted to it even at its source. That stands as one of the axioms of sanitary science to-day. (2207.)

In 1898 the witness made a special study of typhoid fever in Pittsburg. Acting on the advice of one of the most eminent engineers of the time, the city had introduced a water supply drawn mainly from Allegheny River and partly from the Monongahela. The important points of pollution lie at considerable distances above Pittsburg, but as the Allegheny is a swift stream the infectious material is borne down in a comparatively fresh state. As a result of the study, a filtration plant was recommended for the Pittsburg water supply, for the reason that infectious materials might be brought to the intake from points as far distant as Oil City 113 miles or more. (2208.)

Another very serious epidemic due to pollution on the drainage area of a public water supply occurred at New Haven, Conn., in 1900. The city gets a part of its water supply from a sparsely inhabited drainage basin. The large storage reservoirs had been drawn low during

severe winter weather, and when the spring thaw and heavy rains came some feces from a house on the basin where there had been a very few cases of typhoid fever were washed down into one of these reservoirs. The result was that the infected water passed quickly to the city and there were 470 cases of typhoid fever in the spring—not in the fall, when typhoid in communities generally occurs. (2209.)

The recent epidemic at Ithaca, N. Y., arose from conditions very similar to those at Plymouth and New Haven. It was a serious epidemic of about 1,000 cases, with a high death rate. (2209–2210.)

The witness then referred to typhoid fever in Chicago and to the conditions at Detroit, Cleveland, Buffalo, and Niagara Falls. He had found in Buffalo a prevailing feeling among medical men that the time was at hand when the city must purify her water because of the pollution discharged into the lake at Cleveland and higher points. Niagara Falls was suffering severely from typhoid fever, which the local physicians believed to be derived from sewage that had run down Niagara River from Buffalo and higher points. It is a question whether the people who are using the Great Lakes as a water supply must not give them up after a while. The growth of opinion is more and more toward the idea that it will not do to trust to self-purification. It used to be thought that running water when it became thoroughly aerated was pure, especially if it came from long distances. That was the theory on which Pittsburg put in its waterworks and on which Lowell took the obviously sewage-polluted water of the Merrimac and used it for water-supply purposes; but these cities and all others that have trusted to that theory have been typhoid ridden. It is not to-day so much a question of distance as of time during which the germs may settle out or die; in other words, it is a matter of quiescence. "You have got to eliminate all idea of distance from these things and bring in the question of time largely, and that is what I have stated in my treatise on sanitary science and public health, written two or three years ago. It is nothing that I have got up for this case; * * * it is a fact that is borne in upon me by long experience, and I believe that in that respect I stand entirely square with the sanitarians of the world. At any rate, I hold that opinion myself." (2210–2212.)

An increased amount of infectious pollution has no effect on the time needed for purification, but the degree of danger is increased. One microbe coming down from Chicago and resting in the slack water of the Illinois would certainly die if it lay there long enough; but if a million came down, the chances are that some might be carried on by a freshet before they died and the danger would be greatly enhanced. Other things being equal, the greater the amount of infection the more serious the danger. (2212.)

The aeration received by the water flowing over Niagara Falls does not change the amount of pollution which the river contains. The late Prof. Albert R. Leeds repeatedly analyzed the water both above and below the falls and found it to be in exactly the same condition in each place. (2212–2213.)

The witness stated that after a careful consideration of the whole subject, including the typhoid-fever conditions in the sanitary district of Chicago, the sewer outfalls, the amount of sewage, and existing conditions in Desplaines, Illinois, Mississippi, and Missouri rivers, he believed that beyond a reasonable doubt the principal portion of the increase of typhoid fever in St. Louis since January 1, 1900, had been due to the pollution of the water of St. Louis by the Chicago sewage. The typhoid rate of St. Louis from 1895 to 1899, inclusive, compared very favorably with the rate in Lowell and Lawrence, Mass., after the introduction of pure-water supplies at these two places. (2213–2215.)

In reply to the question whether or not the Illinois River water containing mixed sewage and canal water from the Chicago sanitary district had been rendered less safe since the opening of the drainage canal than before, the witness testified substantially as follows:

In the first place we must consider the matter of dilution. The addition of an amount of lake water equal to 5,000 cubic feet per second at Lockport unquestionably dilutes the Chicago sewage and Chicago River is clearer and better than it was before. At the same time it must be borne in mind that the water thus used for purposes of dilution is not the unpolluted water of Lake Michigan. It is drawn chiefly from the mouth of Chicago River and vicinity and has long been known to be polluted more or less. The problem then in part resolves itself into this question: "Does the dilution of a presumably infected sewage by a presumably often infected water contribute to the purity of Illinois River?" The infectious materials that were formerly put into Chicago River are now carried with comparative swiftness down the drainage canal and into Desplaines and Illinois rivers. We have then to consider whether sewage as described, carried quickly and in considerable volume into Illinois River, does or does not render that river safer than before. The belief of the witness, based on the effect of time as a purifying factor, was that it is at least very doubtful whether the pouring of the Chicago sewage into Illinois River does at any time improve that river. This opinion was strengthened by considering the larger amount of sewage now delivered, the opportunities for sedimentation, the susceptibility of Illinois River to freshets, and the changed conditions brought about by the introduction of this fresher sewage with a larger volume of water. Undoubtedly at

times the dilute sewage may have improved the appearance of the river water and may seem to have improved its quality; but if the condition throughout the year, at all times and seasons is considered, it is doubtful whether such improvement has taken place. (2216–2217.)

The witness believes that the danger to St. Louis is practically constant, inasmuch as it can never be known at what moment infectious material may arrive from the sewers of Chicago. It is not supposed that such material is arriving every minute or every hour, but no one can ever know when it may come. The danger is believed to be immediate in the sense that it is urgent and serious, and it is impending by reason of the fact that it is hanging over the citizens of Missouri on the shore of Mississippi River all the time. It is as if ever since the opening of the drainage canal there had been located on the drainage area of the Mississippi a big additional city, notorious for its typhoid epidemics and its high typhoid death rate, and as if the placing of that city virtually on the Mississippi basin had introduced a new element into the life and welfare of the people on the river below. It is no trifling matter to take on a city of that size and add its sewage to a stream already sewage polluted. The danger line must by that addition be reached sooner by those who use the water, and it is for that reason that the danger is regarded as impending, immediate, aggravated, and continuous. (2217–2218.)

Dams undoubtedly favor purification so far as they produce slack water or quiescence, but if the sediment or sludge is allowed to remain on the stream bed, the chances are good that in freshets it may be returned to the current, travel with it, and produce trouble below. The witness cited as an example the Merrimac, which is often in dry seasons a series of mill ponds in which sedimentation goes on, but in the event of a thunder shower or any sudden precipitation sufficient to upset the stream it begins to rise, scouring takes place, and trouble may ensue, as was the case at Newburyport. Epidemics at Lowell and Lawrence have generally followed freshets in the river. It is a general principle that dams are useful, but not sufficient to bring about complete purification. (2218–2220.)

The witness stated that the rate of growth in population of the Chicago sanitary district exceeds that of any other area in the Mississippi basin. The growth in rural population in this basin during the years 1890–1901 was less than 1 per cent, that in the urban population outside the sanitary district of Chicago was 28.2 per cent and that of the city of Chicago was 54.4 per cent. Such a growth in the city population, accompanied by a corresponding dilution of its sewage through the drainage canal, must obviously quicken the flow of Illinois River and bring the infectious materials more rapidly to the people of Missouri. It is as if Chicago should be gradually

moved toward St. Louis. The larger Chicago gets, the nearer it practically comes. It is of interest not only to St. Louis and to Missouri, but to Illinois and to cities and towns that are bound to grow up in the Illinois valley, that if Asiatic cholera or any other disease capable of being water borne should appear in a Chicago five times as big as the present city, it would be a menace to the welfare of the inhabitants of these places lower in the valley very much greater in proportion than the existing danger. Even if Chicago should purify her water supply and reduce her typhoid-fever death rates, the mere existence of this large number of beings pouring their sewage down the Mississippi Valley, no matter how good their general sanitary conditions might be, would be a very serious item in the welfare of these places, because epidemics sometimes appear even in communities having good water supply and good sanitary conditions. (2220–2223.)

In reply to specific questions, the witness stated that the construction of the Chicago drainage canal had added to the sewage-producing population tributary to Mississippi River above the St. Louis water intake a number equal to about 63 per cent. Only municipalities having 4,000 inhabitants or more being considered, the population tributary to Mississippi, Missouri, and Illinois rivers, exclusive of the sanitary district of Chicago, was 2,695,782, distributed as follows: Missouri River, 1,090,832; Mississippi River above the mouth of the Illinois, 1,219,645; Illinois River, 385,305. (2235–2236.).

The witness then stated that there were well-known cases where settling basins holding suspected water for long periods had failed to protect the people from typhoid fever. At Covington, Ky., the water of Ohio River, more or less polluted, is kept at times as long as thirty-two days, and yet Covington suffers severely from typhoid fever, due apparently to infected water. At New Albany, Ind., the storage is about a month in the sedimentation basin, and here also typhoid fever is prevalent. (2238.)

Counsel for the complainant then propounded a long hypothetical question to the witness with reference to the relative effect of the discharge of sewage from Chicago through the drainage canal and from all the other large cities on the drainage areas of the Missouri, upper Mississippi, and Illinois, exclusive of the Chicago sanitary district. The cities, population, distance from St. Louis, the rivers into which the respective sewages were discharged, and the number of deaths from typhoid in each city were included in the question and are given in Table 42. (2239–2249.)

TABLE 42.—*Population, deaths from typhoid, etc., in cities in Missouri, upper Mississippi, and Illinois drainage basins.*

MISSOURI DRAINAGE BASIN.

City.	Population.	River receiving sewage.	Distance from St. Louis.	Deaths from typhoid.									
				1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	1901.	1902.
St. Charles, Mo	7,982	Missouri	47	.....	.....	.....	.....	.....	.....	22	5	6	14
Kansas City, Mo	163,752	.....do	403	59	37	34	29	38	49	52	49	58	58
St. Joseph, Mo	102,000	.....do	501	20	22	31	19	13	19	37	20	12	13
Omaha, Nebr	102,552	.....do	676	22	40	29	18	22	32	26	24	23	22
Council Bluffs, Iowa	25,802	.....do	676	5	7	6	8	8	6	11	6	6	8
Lincoln, Nebr	40,169	Platte	745	33	21	23	15	14	12	13	4	13	10

UPPER MISSISSIPPI DRAINAGE BASIN.

Quincy, Ill	36,000	Mississippi	148	21	28	25	13	13	7	6	10	14	17
Keokuk, Iowa	14,041	.....do	185	8	13	2	3	7	9	9	10	4	8
Burlington, Iowa	23,201	.....do	225	8	10	8	13	3	4	8	13	12	11
Rock Island, Ill	35,300	.....do	310	15	13	3	13	.....	.....	10	14	28	5
Davenport, Iowa	35,254	.....do	310	5	6	4	3	5	2	12	14	11	11
Moline, Ill	7,987	.....do	313	7	9	8	11	3	5	20	22	16	7
Des Moines, Iowa	62,139	Des Moines	387	22	29	30	14	20	17	13	7	22	2
Minneapolis, Minn	102,718	Mississippi	707	134	107	88	60	148	86	71	13	121	6
St. Paul, Minn	163,055	.....do	694	51	32	38	37	22	43	30	30	24	1

ILLINOIS DRAINAGE BASIN.

Peoria, Ill	56,000	Illinois	198	.....	.....	.....	13	18	18	12	23	15	1
Springfield, Ill	34,159	Sangamon	191	.....	.....	.....	.....	.....	.....	.....	20	10	
Bloomington, Ill	23,286	.....do	238	12	14	15	9	10	10	9	15	9	1
Decatur, Ill	20,754	.....do	246	5	7	2	....	2	5	7	11	5	
Ottawa, Ill	10,588	Illinois	282	2	5	2	2	4	4	3	3	5	
Joliet, Ill	29,000	Desplaines	322	12	14	....	12	12	15	13	13	13	2
Pekin, Ill	6,420	Illinois	188	.....	.....	.....	.....	.....	.....	.....	2	1	
Elgin, Ill	22,433	Fox	348	5	3	5	14	....	4	5	15	15	
Aurora, Ill	24,147	.....do	328	6	12	19	10	5	10	4	17	11	
Havana, Ill	3,268	Illinois	.....	3	7	2	5	.....	.....	.....	.....	1	
				.....	.....	.....	.....	369	357	385	338	442	3
Chicago, Ill	[a] 1,500,000	Drainage canal	408	.....	.....	518	751	437	636	442	336	509	8

[a] Estimated.

The question continued as follows:

Assuming that the total number of deaths from typhoid fever on said watersheds i all other towns and cities of 4,000 population and over have not increased for said yea in any greater or different proportion than in the cities above mentioned;

Assuming that the three rivers mentioned run through alluvial soil principally, an the Illinois River enters the Mississippi at Grafton, 29 miles above the Chain of Roc intake tower of the St. Louis waterworks, that the Missouri River enters the Mississip 23 miles below Grafton and 6 miles above the intake tower * * * located on t Missouri side of and in the channel of the Mississippi River about 1,500 feet from t Missouri shore;

Assuming that the city of St. Louis obtains its water from the Mississippi at t intake tower, * * * by which it supplies its citizens, about 600,000 in numb with water for drinking and domestic purposes, and that no substantial change in t method of taking said water or treatment thereof has occurred since January 17, 19

Assuming that the sewage of 1,500,000 inhabitants of Chicago has, since January 1 1900, been discharged into the Chicago drainage canal at Lockport, 291 miles abo Grafton, and that the sewage-polluted water from said city and canal has continual since said day proceeded into the Desplaines River at Lockport, and that the D

plaines enters * * * Illinois River, forming a continuous water course from Chicago to the Missouri shore of the Mississippi River and to St. Louis;

Assuming that in the years 1895 to 1902, inclusive, the number of deaths in Chicago from typhoid fever was [as indicated in above table]; and

Assuming that in St. Louis for the years 1900, 1901, and 1902, and to this day, the percentage of annual typhoid-fever mortality to total mortality has increased about 73 per cent over and above that of the years 1895, 1896, 1897, 1898, and 1899, and that the typhoid deaths in all towns and cities over 4,000 inhabitants were about the same per [unit] population as those given above on the watersheds of said three rivers during said time, and that on the ordinary basis of computing sanitary population by taking the aggregate population of all towns and cities of 4,000 inhabitants or over on the watersheds named, there was a population as follows: On the Missouri watershed, 10,901,832; on the Mississippi above Grafton, 1,219,645; on the Illinois River, exclusive of the sanitary district of Chicago, 385,305;

State what, in your opinion, the sewage from 1,500,000 people of Chicago discharged into the drainage canal had to do with the increased death rate from typhoid fever in St. Louis, as above stated.

The reply of the witness to this hypothetical question was as follows:

After having carefully considered the question and the assumptions which it contains, and in view of my studies of the typhoid-fever statistics of the city of St. Louis to which I referred in my testimony of yesterday, * * * I believe that beyond all resonable doubt the principal factor of the annual increase of typhoid-fever mortality of the city of St. Louis since January 1, 1900, has been due to the pollution of the water supply of the city of St. Louis by the unpurified sewage of the sanitary district of Chicago. (2250)

In closing the direct testimony the witness asserted that, in his opinion, no competent expert either can or will say that any means exist at present by which the unpurified sewage of the sanitary district of Chicago can be warded off from the people on the Missouri shore and the citizens of St. Louis in the event of a period of low water in Missouri River synchronously with a flood on the Illinois basin. (2253)

CROSS-EXAMINATION.

An important point brought out in the cross-examination was the opinion of the witness that even if all the sewage from the sanitary district of Chicago were eliminated from the Illinois River basin, leaving only the pollution otherwise entering the Illinois and that in upper Mississippi and Missouri rivers, the water entering the intake of the St. Louis waterworks would still certainly be polluted and dangerous to the people of St. Louis and the towns below; and that so far as purification of this water by filtration or other means is concerned the cost thereof would not be materially affected by the addition of the sewage from the Chicago sanitary district. (2254–2258.)

During the cross-examination the statement was made by the witness that the chemical examination of water for the purpose of determining its potability is useful under some but not all circumstances. If the

water be grossly polluted, no great skill is required; if only slightly polluted no evidence of value would be produced by the analysis. The same is true of bacteriological evidence. Both kinds of evidence would be preferable to either alone, but the combined testimony is subject to the same conclusion, namely, that pollution would be sometimes indicated and sometimes not. (2258–2260.)

The witness stated that the addition of 1 gallon of typhoid-infected sewage to Mississippi River at Alton might make the water of St. Louis dangerous to drink. He was then asked if the same would be true of St. Charles, Kansas City, and Omaha, stating in reply that he would consider that the water into which such sewage was emptied would be unfit for drinking purposes when it reached St. Louis. In explaining his answer the witness stated that it is hard to draw the line in cases of this kind, as it always is in sanitary matters, and that if the sewage pollution were to take place only once he would not ordinarily consider the water unfit for drinking. There is a point in questions of this kind where it is a very difficult matter to decide; chemical and bacteriological evidence and the conditions of purification en route should be taken into consideration. (2263–2266.)

The longest well-established distance which typhoid germs are known to have traveled to cause infection in water supplies was stated by the witness to be 57 miles, in the case of the Detroit epidemic. The greatest assumed distance for such a journey was 113 miles, from Oil City to Pittsburg. In fact, no limit may be placed on the distance that a typhoid bacillus may travel in water and retain its virulence, if the rate of travel is fast enough. In the present state of knowledge the witness was unwilling to set any limit of distance, but the real problem was, according to him, based not so much on the distance as on the time. (2270–2271.)

The witness then discussed the process of calculation by which he reached his results of typhoid-fever mortality at St. Louis. The ratio of the total number of deaths from typhoid fever to the total number of deaths from all causes gives the percentage of mortality for that specific disease. In the case of St. Louis the statement of 73 per cent increase in mortality from typhoid does not mean that the number of deaths from this disease since 1900 was increased by 73 per cent over the number of deaths from the same disease during the five years previous, but that such increase had taken place in the percentage of typhoid deaths to total deaths in the two periods. In other words, the typhoid death rate is based on the total number of deaths, a definite factor, rather than on the population, an extremely indefinite and fluctuating factor. In the present case a percentage of mortality was computed for each of the years specified. The deaths for the five years 1895 to 1899, inclusive, were added together and divided by five, and those for the years 1900, 1901, and 1902 were

added and divided by three, and the results were compared, showing that the increase subsequent to January 1, 1900, was 73 per cent. There are, according to the witness, various ways of getting at the relative efficiency of any particular disease as a death agent. The quickest way is to compare the total number of deaths from that disease with the ascertained or estimated population. This is what is known as the death rate from that disease, always a more or less uncertain factor. On the other hand, it is generally held that the total number of deaths is ascertained in most cities with considerable precision. (2293–2295.)

In response to the question, "Suppose that a certain identified quantity of water should require in its transmission from the outlet of the sanitary district canal into the Illinois River to Grafton five weeks, would you say that the typhoid bacillus might live in that given body of water?" the witness answered in the affirmative. The same answer was given with the time specified as five months. With reference to a time interval of one year the witness stated that he could conceive of conditions which might prolong its life to that extent. For example, the pouring of a large quantity of acid from manufacturing wastes down the canal during that year might conceivably destroy the typhoid germs in the water and in the sediment. On the other hand, the discharge of an unusual amount of organic matter from the stock yards might so enrich the water as to sustain the life of the germ perhaps even longer than one year. The fact is that the conditions which must be considered in a case of this kind are so many that it is impossible to make categorical deductions which will have any real value. The chances are good that the greater part of the germs would die, but the possibility remains that some might still be alive if they came from sewage under the conditions existing on Illinois River. In reply to the same hypothetical question with the time fixed at fifteen months, the witness replied: "I should say that in regard to a period beyond a few weeks or months that in general the mortality among the typhoid bacteria would be heavy, but that I should never feel certain, even after one or two years, or possibly longer, that some of those were not still living there. (2315–2316.)

In reply to a direct question, the witness stated that he attributed the typhoid fever in St. Louis during 1895 to 1899, inclusive, to a variety of circumstances, each of which probably played its proportionate part in making up the total. The water may have contributed to the net result; also milk, oysters, and secondary infection. Other infected foods, such as water cress, celery, and unwashed fruits, had an important bearing; also flies and all similar factors, each of which tends to keep up in all cities of the world a small but rather constant amount of typhoid fever. The witness asserted that the increase of typhoid

fever subsequent to January 1, 1900, was not due to an overindulgence in oysters on the part of the inhabitants, while there was no doubt that some typhoid-infected oysters may have been eaten in St. Louis during those years and may have caused some cases of typhoid fever. The amount of increase of the disease subsequent to January 1, 1900, in view of the size of the city, would mean, if attributed to oysters, so vast a change in the habits of the people or in the condition of the oyster supply of the United States, that such a theory would be unreasonable, particularly as oyster-caused epidemics are not frequent and are local, while the rise in typhoid fever in St. Louis has been persistent. (2328–2331.)

The agency of wells in St. Louis as a factor in the distribution of typhoid fever was then discussed by the witness, who stated that his investigations showed that there were about 2,000 wells in use, and that the chances are that many of them were infected; but a consideration of all the circumstances, so far as they could be learned by making careful inquiries as to changes in the customs of the people after January 1, 1900, would put the investigator in a position to say positively whether the increase in typhoid was due to any such cause. The witness had considered the subject of the number of wells and whether such number was materially changed after the date mentioned, and had come to the conclusion that there was no reason to believe that any material change in the habits of the people in regard to the use of such wells had occurred since that date, and that, therefore, this agency may be entirely excluded as a factor in causing any portion of the increase. The witness affirmed that he was justified in making this statement, even though he had made no personal inspections of any wells or outhouses and did not know how many people drinking well water had contracted the disease.

Continuing, the witness stated that the theory of well water as a factor in the production of typhoid fever had, in his opinion, been overworked, and that the danger of well waters had been greatly exaggerated in public belief. In his extensive bacteriological experience he but very seldom had had occasion to attribute to infected wells epidemics of typhoid fever, and had never seen an epidemic of any considerable size from such sources. From his experiments made for the State board of health of Massachusetts on the purifying power of earthy materials he had found that as a rule the passage of infectious materials through open soils removes all traces of infection. If the soil is not open, obviously infection can not pass. The only case, in the judgment of the witness, in which privies and cesspools are dangerous to wells are those in which the soil is either very open or cracked or fissured in some way. In view of all these facts, and in view of the further fact that no material or essential change had taken place in the habits of the people of St. Louis since January 1, 1900

the witness excluded altogether the wells as an element in the typhoid-fever increase. While they may have contributed to keep up the usual small amount of this disease in St. Louis, they formed no factor in the large, steady, and continuous increase since January 1, 1900. The witness stated that his investigations showed that the characteristics of this disease in St. Louis are such as might be expected, and have in fact been present, in epidemics due to infected water supply. In the rare instances in which epidemics have been traced to wells, the deaths are numerous within a short period—bunched together, so to speak, both as to time and place. Even on the assumption that the wells in St. Louis might be contaminated with typhoid, it would be a comparatively easy matter to ascertain and demonstrate the fact that the disease was derived mainly from the general water supply, for if it were caused by infected wells, inasmuch as it is absolutely inconceivable from a sanitary standpoint that any very large number of wells should be infected, the vital statistics must then show a much larger number of deaths in restricted localities than ever before, but so concentrated in time as to pass like a wave over these localities, whereas no such waves could be recognized in the present case. (2341–2353.)

In response to the question whether or not the witness would, as a sanitarian, have recommended to the citizens of St. Louis the Mississippi water in its unpurified state as a water supply at any time previous to 1900, he stated that he probably would not have recommended it at any time for drinking purposes without treatment or purification, inasmuch as one could never know with any precision or certainty that the specific disease germs derived from the sewage emptied into the river at different places above on the drainage area had been effectually removed, and inasmuch as the stirring of sediments by steamers or by fishermen might at any moment convert what would otherwise be a well-purified stream into one of danger. (2362–2363.)

REDIRECT EXAMINATION.

The witness referred to his use of the term "normal" as referred to the rate of typhoid fever in a city, and classed it as objectionable, substituting the word "residual" in its stead. He explained that in using the word "normal" he was simply trying to arrive at a good scientific expression for subsequent use. If it should appear that the typhoid fever remaining in a city conformed comparatively with the amounts remaining in other cities having good water supplies, such a remnant or remainder might well be called the residual typhoid and represents the typhoid which will occur in any community sporadically and without reference to any particular source. (2379–2380.)

He then pointed out, in response to questions, that during 1897, 1898, and 1899, the number of deaths from urban typhoid on the

drainage area of Mississippi River above St. Louis, excluding the sanitary district of Chicago, was about 1,100, and that the fatality in typhoid being assumed as 10 per cent, this represents at least 11,000 cases for the three years under consideration. In the sanitary district of Chicago during the same years there were 1,515 deaths from typhoid, which would mean, when calculated on the same basis, 15,150 cases, or 4,000 more than occurred in all the remainder of the Mississippi drainage area above St. Louis. The witness further pointed out that the number of deaths from typhoid on the Mississippi drainage area, exclusive of the sanitary district of Chicago, during 1900, 1901, and 1902, was 1,144, representing an estimate of 11,440 cases, while the number in the sanitary district of Chicago was 1,647, representing 16,470 cases—an excess in Chicago of about 5,000. The witness expressed himself as greatly impressed with this comparison, as it showed that by the diversion of the Chicago sewage into Illinois River the morbidity from typhoid fever in the Mississippi drainage area above St. Louis had been increased by considerably more than 100 per cent.

On being asked to reconsider his assertion made in cross-examination that the cost of filtering the St. Louis water supply would not be materially increased by the addition of the pollution derived from the drainage canal, the witness stated that on reflection he realized that he did not sufficiently consider the fact that, aside from the masses of filth that might be washed down in certain cases and that would add somewhat to the cost of cleaning and care of the filter, there would be the necessity for a much keener watch of the filters and for more intelligent management, so that it might make a difference between the employment of a low-salaried and a high-salaried man as resident manager of the works. Then there was the further contingency that with the unexampled increase of population in Chicago the Illinois and the Mississippi above Chain of Rocks might be reduced to an open sewer, and that under such conditions a single filtration of the water might not suffice. The witness admitted that this condition could not take place for a long period of years and until a vast population was added to that already living in Chicago; but, summing up the analogous cases in the United States in which pure streams had been reduced to a condition of hopeless pollution, stated that it was precisely these long looks into the future which should be taken in cases of this kind. Furthermore, in view of the facts that the low-water flow of Mississippi River at St. Louis is something like 40,000 cubic feet per second, and that Chicago is already pouring down 5,000 cubic feet per second in dilute sewage, while the drainage canal is built to discharge, eventually, 10,000 cubic feet per second, it is well to inquire what will be the effect of discharging that amount of water and sewage into Mississippi River,

which is at times flowing only 40,000 cubic feet per second. At such times the danger line will be approached, and it is not at all inconceivable that when 10,000 cubic feet per second are poured down, the presence of this material in the Mississippi, itself growing more polluted meanwhile, may bring about or help to bring about at certain seasons of the year a condition approaching that of a septic tank, when the dissolved oxygen will begin to decrease and the water will begin to degenerate into a condition of dilute sewage. All these things would add to the cost to-day and would involve a greatly increased cost in the near future; within fifty or one hundred years they might even amount to such a pollution of Mississippi River in low-water times as to make it an impossible source for any modern civilized city. (2381–2385.)

Professor Sedgwick was recalled to the stand to testify concerning the epidemic at Cumberland, Md., which was generally believed to have been the cause of an increase in the typhoid-fever rate at Washington, D. C., through the infection of Potomac River, from which Washington takes its water supply, and on which Cumberland is situated, about 175 miles above.

From the testimony of the witness it appears that there were, in 1890, at Cumberland, 98 deaths from typhoid fever, distributed as follows: January, 18; February, 27; March, 39; April, 8, and May, 5. The number of cases reported in this epidemic was 485, which was believed by the witness to be entirely too small, as the number of deaths indicates that, with the usual fatality of 10 per cent, the total number of cases should have been about 980. The sewers of Cumberland, so far as sewerage was provided, emptied into North Branch of Potomac River and into Wills Creek, a tributary of North Branch at that point. In addition to the sewers, there were an unusually large number of privy vaults set directly over the river or its tributaries. The result of this epidemic was a large increase of the disease in Washington, and this was pronounced by the witness to be one of the most important examples on record of the transmission of typhoid-fever germs over long distances. Beginning in March, 1890, the number of deaths was as follows: March, 19; April, 11; May, 13; June, 33; July, 36; August, 28; a total of 140, exceeding the normal rate in Washington by about 100 per cent and indicating an incidence of the disease amounting to about 1,400 cases. (2759–2761.)

This instance, according to the witness, is particularly interesting by reason of the fact that Cumberland is about 175 miles from Washington, and because the river is of such a character as to offer a good example of a stream neither very swift nor very slow, but having occasional areas of what might be called slack water. The epidemic at Cumberland must have afforded a heavy infection of the stream, although it is a fact that at that time the city was not thoroughly sewered. It is, however, peculiarly arranged with reference to the water

courses flowing past or through it. It is at the junction of that portion of the river which comes down from the Allegheny Mountains and another portion which comes from the West Virginia hills. One other fact of great importance should be mentioned. Between October 4, 1899, and March, 1890, the sedimentation basin and the distributing reservoir in Washington were out of service, so that during that period the water of the Potomac was delivered to the citizens of Washington without purification of any kind. As a result of the pollution of Potomac River, Congress authorized and provided for the construction of a filtration system for the city of Washington. (2761–2763.)

GEORGE W. FULLER.

DIRECT EXAMINATION.

George W. Fuller was called as a witness in behalf of the complainant, and in qualifying stated that he was a sanitary expert, professionally educated at the Massachusetts Institute of Technology and at the University of Berlin. In connection with his work in Germany, he studied bacteriology at the Hygienic Institute and in the private laboratory of the engineer in charge of the filtration plant of the Berlin waterworks. After returning from his European studies he was for five years in the service of the State board of health of Massachusetts the greater portion of that time being spent at Lawrence, where there is an experimental plant, conducted with a view to finding the best ways of purifying sewage and water. During most of his stay at this experimental plant he was in immediate charge. For four years after leaving Lawrence he worked in the valley of Ohio River at Louisville and Cincinnati, being engaged in studying the best means of purifying the polluted Ohio River water at those cities. Since finishing the Ohio River work he had been in private consulting practice and had made investigations at upward of twenty-five or thirty cities, among which are a number of the most important cities in this country, such as Washington, D. C.; Springfield, Mass.; New Haven, Conn.; Oswego N. Y.; Meadville, York, and Columbia, Pa.; and the group of cities lying directly west of New York, furnished by affiliated water companies, including Paterson, Passaic, Jersey City, and Hoboken. The witness further stated that he was a member of the American Society of Civil Engineers, the American Chemical Society, the Society of American Bacteriologists, the American Public Health Association the American Waterworks Association, and the American Society of Naturalists, and that in connection with his membership in the American Public Health Association he had been chairman of the committee on the pollution of public water supplies and of the committee on standard methods of water analysis. (2602–2605.)

The witness gave the following facts in regard to the water supply of St. Louis: The Mississippi for many years has been the source of the

St. Louis water supply. Thirty years or more ago the municipal water department established an intake at Bissells Point, near the present Merchants Bridge. At that place four settling basins, each having a capacity of about 15,000,000 gallons were provided. The water from the river was pumped to these basins, in which it was settled—that is, partially clarified—and partially purified, and then it was pumped into the distributing mains that conveyed it to the citizens of St. Louis. These works continued in service until the autumn of 1894. For about ten years preceding that time attention had been given to the subject of locating a new point of intake, and as soon as the enabling acts were passed construction was commenced of the works as they now exist at Chain of Rocks. The object of moving the intake from Bissells Point to Chain of Rocks, 8 miles or so upstream and about 6 miles below the mouth of the Missouri, was to avoid all possibility of sewage pollution such as had been caused at Bissells Point by the inhabitants of the northern district of St. Louis where the population had increased rapidly since the time that the Bissells Point plant was constructed. (2606.)

At Chain of Rocks a tunnel is constructed through the solid rock, extending out from the Missouri shore about 1,500 feet and terminating in an intake tower located on the Missouri side of the main channel of the river; the water entering this intake tower flows by gravity through the tunnel, which connects with a suction well 100 yards or so distant from the shore. From this suction well the water is pumped by the low lift pumps situated in the adjoining station to a series of six settling basins, each of which is about 660 feet long and 400 feet wide and has an average depth of water of about 15 feet to flow line and a capacity of about 29,000,000 gallons. The river water in passing through these settling basins is clarified to a considerable degree, a large amount of the mud found in the raw river water being left in the form of a deposit. A considerable portion of the bacteria are also removed, including those of infectious diseases, if such are present in the raw water.

From these settling basins at Chain of Rocks the water flows by gravity through a masonry conduit leading to the old waterworks plant at Bissells Point, where a portion of it is taken by the pumps in the original station and delivered to the consumers. Since 1897, a part of the water, however, has been taken from this conduit about halfway between Chain of Rocks and Bissells Point, at Baden, where the high-service pumping station is located. At this station a considerable part of the water going to the hilly portions of St. Louis is pumped. (2606–2607.)

The witness stated that no change in the method of treatment of the raw water from Mississippi River had taken place since the late autumn of 1894.

It was his opinion that the best index of the sanitary character of a public water supply is the record of mortality from water-borne diseases in the community using it, and especially the mortality statistics of typhoid fever. It had been his experience that the typhoid statistics are preferable to those of other water-borne diseases, because of the widespread nature and distribution of typhoid, its abundance in those communities supplied with sewage-polluted waters, its well-defined character, and the substantially large percentage of deaths to cases. The witness believed, however, that if Asiatic cholera should become established in this country, it might serve equally well as an index to the character of water. He further stated that the number of typhoid-fever deaths in the United States, based on a conservative estimate, is from 25,000 to 30,000 per year, and that the number of cases will reach more than 250,000 annually. (2608)

The witness then stated that the water supplied to the citizens of St. Louis during the years 1895 to 1899 was what might be called good sanitary water, basing his judgment on the typhoid-mortality statistics. The water entering the intake tower of the waterworks during the same period was what might be called a suspicious water, by which he meant not distinctly a good water, and was in a much less safe condition from a sanitary standpoint than after it had been stored in the settling basins. (2608–2610.)

The witness then reviewed the number of deaths from typhoid fever in St. Louis from 1895 to 1902, inclusive,[a] and went on to state that averaging the number of deaths during the first five years, 1895 to 1899, gives 112 deaths per annum from typhoid fever, while a similar average during the three years beginning January, 1900, is 196, showing an increase in round numbers of about 80 per cent in the number of deaths. The increase of population during that period being taken into consideration and the typhoid-fever deaths being expressed with reference to the number per 100,000 population, there had been an increase since January, 1900, of about 60 per cent. The number of deaths from typhoid fever during the eight years being compared with the number of deaths from all causes, the increase since January, 1900, in the average percentage of typhoid mortality was 73 per cent. The witness then stated that, to speak broadly, there had been an increase during the period from January 1, 1900, to the date of the testimony of about 60 to 70 per cent above the average of the earlier period. Comparing the number of deaths from typhoid fever during the first five months of each year in the two periods, the witness stated that the earlier periods showed numbers very much less than the later. This was particularly true of the year of the testimony, 1903, when there were in January 15 deaths, in

[a] Date given in testimony of W. T. Sedgwick.

February 15, in March 20, in April 17, and in May, up to the date of testimony, 18, indicating an unusual prevalence of typhoid fever. (2610–2612.)

The witness then stated that he ascribed the increased amount of infection to the public water supply and predicated this opinion on the practically uniform distribution throughout the city of the residences in which typhoid deaths had occurred, and the further fact that a careful examination of several other possible sources of typhoid fever showed that no substantial portion of this increase can be explained in that way. Since January, 1900, the sanitary character of the public water supply delivered to the consumers in St. Louis has been less safe than formerly and it could not be classed as good water. As the treatment of the raw water after it left the intake tower had been essentially the same since January, 1900, as before, the witness declared that the change must have come about in the water before entering the tower and at some place above the waterworks. Continuing, he stated that he was generally familiar with typhoid statistics in the large centers of population on the Mississippi watershed above Chain of Rocks. During the periods under discussion there had been at a number of points some variation in the amount of typhoid fever prevailing in different years. To take the typhoid-fever statistics on this watershed, as a whole, excluding the sanitary district of Chicago, it was his judgment, based on the average number of deaths from typhoid per year, that there had not occurred on the natural drainage area of the Mississippi watershed above St. Louis any increase in the number of deaths sufficient to explain to any material degree the less safe condition of the Mississippi water at the intake tower. He considered that the cause of this condition was the discharge of sewage from the drainage canal, containing filth and infection from the city of Chicago. (2612–2615.)

The approximate number of persons sewering into Mississippi River and its tributaries above the waterworks intake at Chain of Rocks, exclusive of the sanitary district of Chicago, was in round numbers, according to the witness, 2,700,000. This figure was based on a separation of the sewerage-contributing population from the rural population by taking the towns of 4,000 and over as representing those which had sewerage systems and contributed sewage directly to the watercourses. Some towns of more than 4,000 population are undoubtedly not provided fully with sewerage facilities, and on the other hand there are a number of towns of less than 4,000 population which have in a limited measure some sewerage. As a practical proposition the amount of sewage contributed by the population in towns of less than 4,000 inhabitants no more than offsets in the aggregate the amount of pollution in the cities larger than 4,000 inhabitants

which do not have sewerage and whose sewage therefore reaches the river indirectly. In making his statement as to the number of people in the aggregate sewering into Mississippi River above Chain of Rocks, the witness intended to include Missouri and Illinois rivers, exclusive of the sanitary district of Chicago. Based on these data, the witness calculated that the increase in population sewering into the Mississippi above St. Louis due to the construction of the Chicago drainage canal was about 60 per cent. (2616–2617.)

The witness estimated that it would require from ten to twenty-five days for the Chicago sewage to flow from Lockport to Grafton, the average time being from fifteen to eighteen days. He considered that typhoid germs may and do live in sewage and polluted water, such as is found in the Illinois River valley, for weeks and even months. The dilution of the Chicago sewage as it flows from Lockport to Grafton by the waters of Illinois River and its tributaries is extremely variable. At times the dilution is considerable; at other times the flow of the canal may exceed that of Illinois River, particularly that of its upper reaches. Consequently there results at times a dilution of the sewage by the river and at other times a dilution of the river by the sewage. Dilution at best does not destroy the disease germs or infectious matter. Its effect is simply to minimize the danger to those who drink the water so diluted. One effect of the dilution existing in Illinois River at low stages is to bring to Grafton more quickly than would otherwise be the case injurious matter entering the river at points along its route. (2617–2618.)

With reference to the significance of the ponds, dams, and slack-water stretches found in Illinois River, the witness stated that there are a good many days in the course of a year when the velocities at these points are so low that deposition takes place to a considerable degree. But deposition does not mean permanent elimination from the flowing water. The dangerous substances may be disturbed from time to time by changes in velocity of the stream flow due to small or great floods, or by the passage of boats or the action of the wind. These disturbances cause the bacteria to leave the bed of the river and be carried on to greater or shorter distances, and in this way the germs of disease may pass from the Chicago drainage canal at Lockport to the mouth of Illinois River at Grafton. In fact, the witness stated that it was probable that the water of Illinois River, passing into Mississippi River at Grafton, was sometimes richer in typhoid-fever germs derived from the sanitary district of Chicago than the water running over the Bear Trap dam. Such a condition of affairs might arise at times through disturbances of the sediment lying upon the bed of the stream in places. As the typhoid germs are returned to the flowing stream from their position on the bed an accumulated result is effected, whereby, at times at least, the waters of Illi-

nois River flowing to Grafton may discharge the concentrated essence of the infection by taking, in the manner above described, portions of the infection coming from many days' flow through the drainage canal into the river. (2619–2620.)

Continuing, the witness stated that he did not believe it possible for Illinois River water ordinarily to flow by the intake at Chain of Rocks without some of it entering the intake tower. In his judgment, the sewage of the sanitary district of Chicago pollutes and infects the water of Mississippi River along the Missouri shore to such an extent that it makes this water less safe for drinking and domestic purposes than it was before the opening of the drainage canal. This conclusion he believed to be borne out by an examination of the records of typhoid-fever mortality. There were on the drainage area of Mississippi River above Chain of Rocks, exclusive of the sanitary district of Chicago, about the same number of typhoid deaths from year to year between 1895 and the date of the testimony, 1903; but since the opening of the drainage canal there had been added to the drainage area an amount of pollution shown by 1,647 typhoid deaths for 1900, 1901, and 1902, and there was no doubt in the mind of the witness that these added cases had been the cause of the increase in St. Louis. (2621–2622.)

Considering the probable future growth of Chicago and the constantly increasing amount of sewage discharged through the drainage canal, the witness believed that the water in Mississippi River along the Missouri shore would be rendered less safe than at the present time by reason of the increased amount of infection discharged into the canal and the shorter interval of time required for its passage from the canal to Chain of Rocks as a result of the constantly increasing amount of water used to dilute the sewage, which would quicken the flow of Illinois River. At low stages of Illinois and Mississippi rivers it is quite possible, in the opinion of the witness, that the amount of pollution may become sufficient to exceed the amount of oxygen available in the water and to make the two rivers resemble open sewers rather than streams carrying live, natural water. (2622–2623.)

In reply to the question whether or not the Chicago sewage would increase the difficulties of the problem of filtering or otherwise purifying the water supply of St. Louis, the witness stated that, in his judgment, the increased amount of infection adds to the responsibility of treating the water so as to make it perfectly safe and wholesome for the citizens of St. Louis, and that financially there would be the greater expense of the construction of a filtration plant and the added cost of supplies used in connection with its operation, especially in times of low water. It would also mean that filtration works, if

adopted, must at times be operated at lower rates of filtration than if this infection were absent, and this reduction of the rate of filtration would necessitate a larger and hence a more expensive plant to purify the same quantity of water. Looking some distance into the future, and considering the various centers of population tributary to Mississippi River above St. Louis, but excluding the sanitary district, the witness was certain that there will ultimately come a time when single filtration can hardly be expected to produce a satisfactory quality of water at Chain of Rocks. This condition and the time at which it arrives will depend on the rate of increase of population in the communities on the drainage area; but whatever the rate of growth in those communities may be, it is certain that the added infection due to Chicago sewage will hasten the day when single filtration will prove unsatisfactory and when it will be necessary to resort to other methods involving increased expense and responsibility. (2623–2624.)

CROSS-EXAMINATION.

In reply to questions the witness stated, among other things, that if a stream of water flowing 300,000 cubic feet per minute, into which was poured the sewage of Chicago, were started in a tortuous course at the Bear Trap dam, receiving no dilution on the way, it would not, in his opinion, be absolutely freed from infection by the time it reached New Orleans. While there would be a very great reduction in the number of typhoid germs present, there was no certainty of absolute elimination. The witness further emphasized the fact that the self-purification of a stream is controlled by the time and not by the distance which it runs. Speaking absolutely, he believed it to be very doubtful whether there was any such thing as the purification of a stream of running water into which infected sewage is poured. The construction and maintenance of filtration systems for the purification of the St. Louis water were then discussed by the witness, who stated, with reference to the filtration of the Missouri River water as contrasted with that of the Mississippi, that there would not be any material difference in the construction of any unit portion of the filters, but that as the pollution and infection increased a larger area would be required in order to satisfactorily purify the infected water. If he were providing a filter to treat Missouri and Mississippi water without the admixture of that from Illinois River, there would be no necessity for making it larger or more expensive because of the union of these waters. But in the case of the admixture of Illinois River water, although there would probably be no marked difference in the size of the first installation, the reserve portion of that installation would serve for a shorter period of years than would be the case if that water were excluded. With the Illinois water included, it would also

require more skill and judgment on the part of the engineer in charge of filter maintenance. (2624–2633.)

The witness further stated that there were a good many days when the proportion of Illinois River water entering the St. Louis intake is exceedingly small, but to guard against danger arising on those occasions when a considerable proportion of Illinois River water enters the intake, there would be required a constant exercise of care and skill equivalent to that which would be necessary if it were absolutely certain that a considerable proportion of Illinois River water came in constantly.

The cross-examiner then sought to establish the assertion that if it were necessary to provide more expensive filters and maintain a more expensive superintendence because of the discharge of Chicago sewage, the same necessity would arise in case there were a great epidemic of typhoid fever at Kansas City, the infection from which, as admitted by the witness, would reach Chain of Rocks under ordinary conditions in about one week. The apparent purpose was to show that for the safety of St. Louis at all times it would be necessary to provide as expensively for the elimination of sewage naturally running into the Mississippi drainage area as it would for that of sewage artificially diverted through the drainage canal. The witness replied that there would be an added danger from Illinois River, in that it is intermittently flushing out large accumulations of infected sediments, making the water constantly dangerous, whereas in the case of the supposed Kansas City epidemic the danger would not be constant but confined to a single limited period. As a general proposition, the growth of Kansas City is an impending menace to the water supply of St. Louis, but the contingency is remote, while the addition of the sewage from the Chicago drainage canal makes much less distant the day when serious trouble will result from the use of the water at the Chain of Rocks intake. (2639–2641.)

With reference to the sewage pumped from Chicago River into the Illinois and Michigan Canal, thence entering Desplaines River, the witness stated that, in his opinion, prior to 1899 this canal contained infection in a considerable proportion, though a large part of the infection from Chicago sewage remained in Chicago River. When the sewage was pumped into the Illinois and Michigan Canal the organic matter was in so advanced a state of decomposition that the proportion of typhoid-fever germs present compared with that originally present in Chicago River was exceedingly small, particularly as the much diluted contents of the canal flowed into Desplaines River. While this water was not absolutely free from infectious germs dangerous to the people of St. Louis, it was absolutely certain that it was not sufficiently infected to cause any trouble in that city, as evidenced by the low typhoid-fever rate. The Illinois and Michigan Canal was

in effect a septic tank. It encouraged the growth of certain kinds of bacteria which are known to have a destructive influence on the germs of typhoid fever. This septic action, such as occurs in a tank or has occurred in the Illinois and Michigan Canal, does not ordinarily, if ever, take place in the bed of a stream to such an extent that it would affect very materially the life of typhoid germs. (2644–2645, 2652.)

In the course of over a year's investigation of water in Ohio River at Cincinnati, involving practically daily examinations, the witness found *Bacillus prodigiosus* on one occasion. While there is a possibility that others existed in the same water, it is a fact that the bacterium is rarely found in American waters, although it is a very easy germ to discover. (2665–2666.)

REDIRECT EXAMINATION.

With reference to specific instances of typhoid bacilli being traced through the outfalls of the sewers of a city into running streams and conveying typhoid to persons using that water, the witness said that there were many in the sewage-polluted Ohio basin, especially at Louisville. The sewage coming down to Louisville originates almost entirely at Cincinnati, a distance of about 150 miles, and points above. At times of very low flow in the river the velocity is so slight that the period of time required for those germs to pass from Cincinnati to Louisville is more than a month. Nevertheless there was typhoid in Louisville due to the consumption of river water, even though the water had passed through settling basins holding five or six days' supply, in which sedimentation takes place. This, in the opinion of the witness, was a very reliable demonstration that typhoid-fever germs are not absolutely removed from sewage-polluted waters in a period of one month. He cited, further, the instance of Covington, Ky., mentioned in the testimony of Professor Sedgwick, and stated that he considered that there was no room for doubt that a portion of the pollution existing in Ohio River at Cincinnati is due to the sewage from cities located in Allegheny County, Pa., such as Pittsburg and Allegheny, which are 450 to 500 miles by river above Cincinnati. (2666–2667.)

In reply to a question concerning the deposits of sediment in the slack-water places in Illinois River, such as Lake Peoria, the witness stated that there is documentary evidence and practical observation as to the amount of scouring which takes place. He quoted from reports of the Chief of Engineers of the United States Army as follows:

> Channels dredged twenty years ago are but little deteriorated, and it is surprising to find that there has been no deterioration in depth in the pools created by the Henry and Copperas Creek dams after from fifteen to twenty-eight years' use.[a]
>
> The dams [in Illinois River] have no appreciable effect above mid-stage of the river

[a] Rept. Chief of Engineers, U. S. Army, 1895, p. 2716.

when currents are the strongest, so that all lighter sediment is swept away as well now as before the construction of the dams. That there has been no appreciable change felt in the pools of Illinois River is a fact that has been often remarked upon by steamboat men and persons interested in the use of the river since the construction of the first dam at Henry, thirty years ago.[a]

The witness concluded his redirect examination by stating that in his judgment no great amount of sediment remains upon the bed of the stream of Illinois River for any great length of time. (2667–2668.)

GARDNER S. WILLIAMS.

DIRECT EXAMINATION.

Gardner S. Williams, a witness called in behalf of the complainant, stated that he was a consulting water supply and hydraulic engineer of Ithaca, N. Y., consulting engineer of the Ithaca Waterworks Company, and professor of experimental hydraulics in Cornell University, having occupied the latter position since the fall of 1898; that he had been educated in the common and high schools of Michigan and in the engineering department of the University of Michigan, where he took the degree of bachelor of science in civil engineering in 1889 and the advanced degree of civil engineer in 1899, the latter being conferred on him by reason of his extensive studies in connection with water supplies, especially from a sanitary standpoint, water-borne diseases, and investigations of the flow of water, on which he had later been awarded the Normal medal by the American Society of Civil Engineers. He had been connected with the construction of waterworks at Bismarck, N. Dak., and Greenville and Owasso, Mich.; from 1893 to 1898 he was civil engineer to the board of water commissioners of Detroit, where he was in charge of the engineering work connected with the construction of the extensive supply system of the city and made investigations on the flow of Detroit River in the American channel. He was also engaged as consulting engineer in the construction of other systems and planned and constructed additions to the waterworks plant at Ithaca, N. Y. The witness stated that since assuming charge of the hydraulic laboratory at Cornell University, which he claimed to be the most extensive hydraulic experiment station in the world, he had had abundant opportunity to study the flow of waters and their effects on the beds of streams, having conducted extensive experiments on the flow of water in open channels and over dams for the United States Board of Engineers on Deep Waterways, for the city of New York in connection with its investigations of the Croton water supply, and for the New York State canal survey, together with a number of less important investigations instituted by the laboratory itself. At the time of testimony the laboratory was

[a] Rept. Chief of Engineers, U. S. Army, 1898, p. 2436.

engaged on an extensive series of experiments for the hydro branch of the United States Geological Survey. During this t investigated the flow of water at Holyoke, Mass., and Sault Ste. Mich.

The witness stated that he had made investigations of t fever epidemics at Detroit, Saginaw, and Charlevoix, Mich Ithaca, N. Y., and had studied the information published in to epidemics of water-borne diseases in this country and (2418–2421.)

The sewerage system of Chicago was described as a combin tem, receiving both household sewage and washings and filth fr streets of the entire city. The sewers receive the discharges o 1,750,000 people, amounting to about 4,400 cubic feet, or 150 solid human fecal matter every twenty-four hours, which, ac to the witness, was more than 50 per cent of the suspended soli ter at Lockport. The greater portion of this sewage is deliver Chicago River and its branches and carried by way of the d canal into Desplaines, Illinois, and Mississippi rivers; the rem of the sewage is emptied into Lake Michigan. That going t the drainage canal is diluted with Lake Michigan water, take a point directly over the beds of sewage deposit, which are from feet deep. This water is so poor that in the opinion of the wi it were delivered, unmixed with sewage, to a conduit suffic carry it to the Mississippi at Grafton in the same period it takes present mixture to pass downstream to the same point it wo very likely to carry disease infection and would thereby const menace to the health of the people using the Mississippi water Grafton for drinking purposes. (2422–2424.)

Referring to the physical characteristics of Desplaines and rivers, the witness stated that below Lockport the Desplaines rapid fall to Joliet, where the slope becomes materially less and velocities follow. The stream then passes on into the Illinois, has a moderate slope in its upper portion, but as it comes down t La Salle reaches a very flat country, where it partakes essenti times of the nature of an estuary rather than of a river. It lea banks at a stage a little over 10 feet above ordinary low wat overflows large areas, forming basins which temporarily sto flood waters and then return them to the stream. For the pur improving navigation numerous dams have been constructed the stream; these, being intended solely to store water in ti drought, are not of the nature of dams built for power purposes. difference in height of the water surfaces, measured from the cr the dam, in what would be the upper and the lower pools is freq less than half a foot, so that in the case of markedly higher wat dams become submerged weirs. In times of low water they caus

siderable quiescence and an extensive sedimentation of suspended matter results. As depositions occur in flowing water, the heavier materials naturally are deposited first. It is a notable fact that in such a stream the pressures existing in the thin layers of water vary inversely as the velocity; that is, the higher the velocity the less the pressure which the flowing water is able to exert on the water adjacent to it. The velocity in streams is ordinarily rather uniform for some distance below the surface, so that it is easily possible for suspended matter to disappear from the surface of the stream and get into the lower layers. As it approaches the bottom, however, the decrease in velocity becomes more rapid, and hence the increase of pressure from point to point becomes more marked and the sinking particles meet a higher resistance, so that there accumulates at the bottom a layer of water that is highly charged with suspended matter. The lighter particles in the water will be the last to be deposited, and we may say, generally speaking, that the bacteria, which are of very nearly the same specific gravity as that of the water itself, will only be borne to the bottom when entangled with the heavier suspended matter. Therefore such bacteria would be less liable to be deposited than the inert mineral matter. (2425–2427.)

Although it is true that large amounts of sedimented material have been deposited in Illinois River, there are also times when the river scours, or, in other words, takes up such deposited matter and carries it downstream. Observations of the United States engineers who have had charge of the improvement of that river show that there has been no extensive silting up or filling of the channels of the stream, either natural or artificial. It is not necessary to have flood conditions in order that this suspended matter shall be taken up and carried along. Very small changes in the stages of the river make very decided differences in the transportation of this material. The passage of boats also has very decided effects in stirring up these deposits. The witness stated that during his investigations of the flow of St. Marys River he had opportunity to observe the extent to which these variations in the velocity of the stream were felt. There was at that time a channel about 2,600 to 2,800 feet wide and through the major part of its extent the depth was 50 to 56 feet. When a steamer drawing from 14 to 17 feet passed through the channel, the velocities in the stream were disarranged and disturbed for a distance of as much as 100 feet each way from the steamer and extending to the bottom, and this disturbance continued sometimes for as much as half an hour after the passage of the steamer before the water was able to resume its normal regimen. Such effects can not fail to be an important factor in the disturbance of the sedimentary deposits that may be formed along the bottom of a river, and they will lead to the picking up of particles from the highly loaded layer of water next to the bottom. The

lighter particles will of course be disturbed first, and therefore the bacteria will be much more likely to be resuspended and carried farther downstream than the mineral matter. They might be redeposited in some places in the course of flow, but some of them would undoubtedly be carried for very long distances, and in the case of Illinois River would be eventually discharged into Mississippi River. Whether or not their virulence would be diminished would depend on the length of time during which the bacteria might have remained deposited in the bed of the stream, but under such conditions as exist in Desplaines and Illinois rivers, receiving sewage from the city of Chicago, the witness saw no reason to believe that germs so deposited would be destroyed. It seemed to him entirely possible that as a result of the scouring action set up at the bottom of the slack-water portions of Illinois River, the water in times of flood might be more heavily charged with polluted and infectious matter than is the dilute sewage delivered into Desplaines River over the Bear Trap dam. (2427–2433.)

The witness stated that, according to his estimates, during over three hundred days in the year 1900 the water would have flowed from the Bear Trap dam to the mouth of Illinois River in less than fifteen days. The discharge of Illinois River, containing the mixture of Chicago sewage and water, would increase the pollution and infection of the water of Mississippi River at Grafton and render it less safe for drinking and general household purposes. Water so discharged would become mixed with Mississippi River water so as to affect its quality on the Missouri shore. When Illinois River enters the Mississippi at a lower velocity than that of the latter stream, the Illinois water would be drawn or forced to mingle with the Mississippi water in the same way that it is possible to pump water by means of the jet pump, which delivers a jet of water through a channel at a high velocity, entraining with it the slower-moving water at its side. Expressed in more popular language, the principle as stated by the witness, was that the more swiftly moving stream exerts a suction on the water of the slower stream which leads to the dissemination and mixing of the latter throughout the volume of the former. When the velocity of Illinois River is greater than that of the Mississippi, the momentum of the particles delivered to the Mississippi would be such as to carry them well out into the stream. The backing up of Mississippi River water into Illinois River would also have the effect of producing a fairly thorough mixture of the waters of the Illinois and so much of the waters of the Mississippi as backed up into the stream and as the flow of this water which had been stored in the Illinois came out of the mouth of the river, it would have the same effect as a flood rising in the Illinois itself, producing an additional scouring on the bottom of the river. The witness then stated that he was pre

pared to assert positively that at times the waters of Illinois River reach the intake of the St. Louis waterworks at Chain of Rocks. (2434–2436.)

The witness stated that if all the disease organisms discharged into Illinois River through the Chicago drainage canal should become innocuous at Lockport, the discharge would still be a menace to the health of the people of Missouri who used the Mississippi water for drinking purposes, for the reason that this quantity of water added to the stream tends to decrease materially the time required for the flow from various points of pollution along Illinois River, thereby making the infection reach St. Louis in a much shorter time than was required previous to the opening of the canal. Concerning the probable average and probable range of dilution of the suspended matter in the water of Mississippi River flowing past Chain of Rocks, caused by the discharge of Illinois River, the witness stated that his computations showed that during seven months in the year the ratio of the amount of suspended matter delivered into Desplaines River from the Chicago drainage canal and the amount of water flowing in Mississippi River at Chain of Rocks is from five-tenths to 1 part of the suspended matter per million parts of water in the Mississippi, and at a time of low water 1¾ parts per million. This computation is based on the solids which are in suspension in the sewage at the Bear Trap dam and has no bearing on any substances which may be in solution, and therefore do not appear as solids in suspension. (2436–2439.)

The witness then described a case where a similarly polluted mixture of suspended solids from sewage matter had produced typhoid fever, as follows:

The water supply of the city of Detroit is drawn from the American channel of the Detroit River, at the head of the river or at the foot of Lake St. Clair. Detroit River, as you know, is one of the links in the connecting waters between the upper lakes, Huron, Michigan, and Superior, and the lower lakes, Erie and Ontario, and is the natural outlet of the upper Great Lakes to the sea. The water from Lake Huron enters the St. Clair River and flows through it a distance of about 35 miles, to the delta of the St. Clair River, when it discharges into Lake St. Clair. Lake St. Clair is nearly circular in form, being 24 miles wide and, including its delta, about 24 miles in length, measured in the direction of flow. The water supply of Detroit is taken practically from the lake or from the river a few hundred feet below the point where it takes its origin in Lake St. Clair.

In the year 1890 the number of deaths in the city of Detroit from typhoid fever were 9, in the year 1892 the number of deaths from typhoid fever in the city of Detroit were 209. This remarkable increase was such as to cause Detroit for that year to take rank among those cities which have had the highest death rates from typhoid fever in America—there are but one or two of our large cities that have had death rates notably higher than this, one of them being Chicago. An examination of the record showed that this epidemic began in June, during which month there were 38 deaths by typhoid fever. As the civil engineer to the board of water commissioners of Detroit, it was very natural that my attention should be called to this condition

of affairs, as many people attributed the cause of the epidemic to the water supp and I started to ascertain, if it were possible, where such a remarkable infection co have come from so suddenly and so unexpectedly. After an extended investigatio I found that the epidemic was undoubtedly caused as a result of improvements to th channel of Black River, which flows into St. Clair River near its head, at Port Huro a distance of about 57 miles from the intake of the Detroit waterworks. I found th Black River, which was a sluggish stream, having ordinarily no current whatev and only in times of heavy rains a perceptible current, had been for years receivin the sewage from the city of Port Huron, through the center of which it flows. In ord to improve the harbor of Port Huron, which was virtually the lower portion of Blac River, the United States Government had caused the river to be dredged during th early months of 1892, and in the process of that dredging had removed deposits fro near the mouths of the sewers which ranged in depth from a foot to 7 or 8 feet, an according to the testimony of some of those who lived along the banks, to as much 10 feet in depth. This material was loaded upon scows and transported out into th St. Clair River, where it was discharged or dumped into the stream, at a point, I have already stated, about 57 miles above the intake of the Detroit waterworks. found upon further investigation that this work had been begun during 1891 and th conditions were such that this particularly highly infectious deposit of material w reached right at the beginning of the operations in 1892, so that this fully explaine the sudden outbreak of typhoid fever in Detroit, it having been carried through th water of the St. Clair River and through Lake St. Clair to the intakes of the Detro waterworks, and thence distributed to the consumers throughout the city, with th result above mentioned. (2439–2441.)

The time elapsing between the deposit of infectious matter a Port Huron and the arrival of the water into which it was so dis charged and the delivery of the same to the consumers in Detroit as stated by the witness, would be the time required for the wate to flow from the point in St. Clair River where the material was dis charged to the intakes of the Detroit waterworks, which he estimate could not have been less than eight days and was probably about te days. (2443.)

The witness then stated that the incubation period of typhoi fever in about 75 per cent of the cases is from ten to fifteen days, an pointed out the fact that the sum of the time required for the appear ance of infection in Detroit after the dumping of the pollution a Port Huron, the average incubation period, and the ordinary tim elapsing between the onset of the disease and the occurrence of deat agreed within twenty-four hours with the time which had elapse from the deposit of the dredged material to the time when ther were in a single day in Detroit four deaths from typhoid fever, ther having been only one death from this disease during the precedin twenty-four days. (2444–2445.)

The discharge of St. Clair River, according to the witness, varie from 180,000 to 200,000 cubic feet per second. At the time of th epidemic the discharge was about the former amount, which i equivalent to the discharge of Mississippi River at St. Louis durin ordinary stages. Assuming the degree of dilution from such dis

charge, the witness found that during the month of April, 1892, the ratio of volume of dredged material discharged per day into St. Clair River at Port Huron to the volume flowing in said river for twenty-four hours ranged from 0.55 to 1.1 parts of dredged material per million parts of water. The range of dilution of the sewage matter of Chicago in the waters of Mississippi River flowing past Chain of Rocks was stated to be at ordinary stages from 0.5 to 1 part of suspended matter per million parts of water. The witness said that the proportion of suspended matter in the sewage and water at Lockport was something over twenty times as great as that in St. Clair River, while that in the Mississippi at Chain of Rocks, coming from the Chicago drainage canal, was substantially the same as that in St. Clair River at the time of the Detroit epidemic. (2445–2449.)

The witness then described the epidemic at Grand Forks, N. Dak., substantially as follows:

The main sewer of the city of Crookston, Minn., became damaged so that it failed to discharge the material delivered into it. This led to the accumulation of deposits of sewage matter in the sewer, and to afford a temporary relief a small connection was made around the break, which carried off a portion of the liquid matter of the sewage and discharged it into Red Lake River, the regular outlet for Crookston sewage. In the fall of 1893 this sewer was repaired, and November 17 the sewerage system of Crookston was flushed of the accumulations which had gathered during the several months preceding. Typhoid fever to the extent of about 60 cases had existed in Crookston in October and November. At the time of the flushing of these sewers and the consequent delivery of sedimentary accumulations to Red Lake River the surface of the river was frozen over. The town of Grand Forks is located on this river about 60 miles below Crookston. In November 2 cases of typhoid fever and no deaths were recorded in Grand Forks, and for months preceding there had been a very small amount of this disease. In December, following the flushing of the Crookston sewers on November 17, 230 cases of typhoid fever and 4 deaths were reported in Grand Forks, in January 712 cases and 52 deaths, in February 231 cases and 27 deaths, in March 46 cases and 10 deaths, in April 26 cases and 2 deaths, and in May 1 case and no deaths—a total of about 1,200 cases of typhoid fever and 100 deaths at Grand Forks as a result of the flushing of the sewers at Crookston. Grand Forks was at that time taking its water supply from the river. This evidence was introduced to show that the infectious material accumulated in the Crookston sewers had retained its virulence and after such a term of storage and a transmission of 60 miles by water had resulted in this great epidemic. (2455–2456.)

In response to a direct question the witness said that it was his opinion, based on his knowledge of the transmission of typhoid fever

through water, the conditions found on investigation to exist along the drainage canal and the streams which unite the sewers of Chicago with the intake of the St. Louis waterworks, and the conditions which have existed in Chicago and St. Louis prior to and since the opening of the canal, that typhoid infection has at times been transmitted from Chicago to the St. Louis intake, and that such conditions might be expected to persist in the future. The best criterion of the sanitary quality of a water supply that is used by a community for domestic purposes is the presence or absence among the people who use it of water-borne diseases, of which typhoid is the most important. The evidence afforded by the typhoid-fever statistics of St. Louis for the period 1895 to 1899 would indicate that the water supply was not ideal. Nevertheless, it would compare favorably with the supplies of a very large number of American cities and would rank with about the second class of American water supplies, as experts usually consider them. The evidence presented by the typhoid-fever statistics in St. Louis subsequent to January 17, 1900, however, showed that the probable infection of the supply had become nearly twice as great and that its rank had materially dropped, judged by the conventional standards of purity. (2460–2463.)

The significance of the sanitary analysis as an aid in determining the presence of infectious pollution was then explained by the witness, who said that if it fails to show anything of a deleterious character, it is nevertheless not to be accepted as an evidence of purity, but if it does show the presence of substances which are recognized as connected with infectious material, then it is to be regarded as a valuable indication of the possibility of contamination. Whenever chemical, microscopical, or bacterial analyses of water indicate the presence of substances that are known to be related to infectious matter, it is proper to give to such evidence great weight in estimating the quality of the water. On the other hand, it is not necessary for the expert to depend on or to require either of these analyses in order to determine the degree of pollution of a water if it is possible for him to see the polluting material flowing into it. (2464–2467.)

The witness then stated that if, with a knowledge of the existence of the conditions at Chicago and along the drainage canal and Desplaines and Mississippi rivers, as they were known to the witness, an "expert" should state that it is impossible for infectious matter discharged by the sewers of Chicago to reach the Missouri shore of Mississippi River and the intake of the St. Louis waterworks and be a source of danger to the citizens of Missouri residing on that shore and using the water from the Mississippi below the mouth of Illinois River for drinking purposes and to the citizens of St. Louis using the water supply drawn through the intake at Chain of Rocks, he (the witness)

would say that the person making this statement had thereby shown such a lack of knowledge of the history of water-borne diseases and the life and phenomena connected with their transmission and infection as well as of the laws of flow of water in open channels as to totally disqualify him as an expert on the sanitary value or quality of a public water supply. The problem before future generations in St. Louis by reason of the discharge of Chicago sewage into Illinois River is far more difficult than that which is to be faced at present. A careful study of the relations existing between the flow of rivers contributing to the water flowing past the St. Louis intake and the prevalence of water-borne diseases in the city of St. Louis among those of her citizens who are using the public supply has led to the conclusion that at the present time the remarkable immunity from serious typhoid infection which the citizens of St. Louis have thus far experienced is due very largely to the character and amount of water contributed by Missouri River. As the Missouri enters the Mississippi the amount of silt in suspension in its water often amounts to over 1,200 parts per million. A large part of this silt is of such a nature as to be readily deposited when the water approaches a state of approximate quiescence; and so vast a quantity of depositing matter can not fail to remove a very considerable percentage of the bacteria that are daily brought into the settling basins. As time goes on, the history of the Missouri will become the same as the history of every other stream on whose shores the hand of man has rested, and while the total quantity of water which that stream will deliver from year to year will remain about the same as now, the amount during periods of drought will be decidedly less and larger portions of the discharge will be gathered in a few floods. The result of this on the water mingling to form the supply of St. Louis will be that in the future Missouri River will show a diminution in the percentage which it represents of the total flow of Mississippi River past the city. It will therefore follow that the amount of silt furnished by Missouri River will be less and less sufficient to remove from the mixed water the number of disease germs, even aside from the certainty that the number of these germs will vastly increase as time goes on. It therefore seems clear that the pollution of the waters of Illinois and Mississippi rivers will have from year to year a continuously greater effect on the healthfulness and quality of the water delivered to the citizens of St. Louis by their waterworks system. In view of this fact, together with the wonderful growth of the city of Chicago, there can be no question that in the future the menace to the health of St. Louis arising from the discharge of Chicago sewage into Illinois River will be much more tremendous and impending than it is at the present time, grave though the present condition may be. (2473–2477.)

CROSS-EXAMINATION.

The witness stated, in response to a hypothetical question, that, assuming the existence of an equal number of cases of typhoid fever at St. Charles, Mo., and at Omaha, Nebr., and a subsequent occurrence of the disease at St. Louis, he would attribute the St. Louis typhoid to infection from both points. The life of the typhoid bacillus in streams is a matter of time rather than of distance, as a general proposition, but it was the opinion of the witness that no stream of water on the surface of the earth flowing in natural channels is long enough to warrant the absolute assurance that the typhoid germ might not live from one end of it to the other. If typhoid-fever germs were discharged into Mississippi River at St. Paul and no other possible source of infection of the waters appeared, they might arrive at New Orleans and infect the water supply of that city. (2547–2549.)

Pages 2551–2583 of the record contain the report of cross-examination directed to the witness for the purpose of ascertaining his reasons for declaring that the increase in the number of deaths from typhoid fever in St. Louis subsequent to the opening of the Chicago drainage canal was due to the discharge from that canal rather than to the discharge of sewage from the numerous cities located on Missouri, Mississippi, and Illinois rivers above the St. Louis waterworks intake. The witness confessed that it was impossible to determine by technical methods whether the virulent typhoid bacilli entering the intake were derived from the sewage of one city or another, but held that such demonstration was unnecessary to substantiate his claim of the culpability of Chicago sewers. Previous to the opening of the canal the water of St. Louis could not be considered safe at all times, by reason of infected discharges from city sewers lying in either one of the streams that converge above the intake, but the records show that the conditions that prevailed during the years previous to the opening of the canal had not been changed except that Chicago sewage had been discharged into Illinois River through the drainage canal. If this canal had not been opened these conditions would not lead one to expect any material increase in typhoid mortality in St. Louis, but the fact that the canal had been opened and Chicago sewage had been discharged into Illinois River, and that within a short time the typhoid in St. Louis had increased and such increase had been persistent, demonstrated that the discharge from the canal is responsible. In other words, the increase of typhoid fever in St. Louis must be due to some change of conditions with reference to the pollution of the St. Louis water supply, and the records of typhoid mortality throughout the contributing drainage area above the St. Louis intake reveal only one important change—namely, that of the added contribution of Chicago sewage. Therefore the observed effect in St. Louis must be due to that single cause.

In closing his testimony, the witness stated that in considering the increase in the typhoid rate in St. Louis since the opening of the drainage canal he had used the records of deaths only. If the number of deaths in St. Louis should show an increase and the number of cases reported show a decrease he would still give attention to the death record because it is the more reliable. He would never base conclusions in a typhoid epidemic on the number of cases reported, because a man never dies but once, and in the case of death, under the laws of the United States, generally a record is made somewhere, whereas a man may be sick of typhoid and no record of it appear. As a matter of fact, it is a rare occurrence for more than 60 per cent of the actual typhoid cases to be reported. Therefore the case record is of no value. (2588–2589.)

TESTIMONY FOR DEFENDANTS.

The testimony for the defense was commenced on board the Illinois fish commission boat *Illinois* July 13, 1903, the boat proceeding up Mississippi and Illinois rivers and stopping at various points at which local testimony was taken. At each point where samples had been taken for examination by the experts to be produced in behalf of the defendants, the local collectors testified as to the manner of taking the samples, identified tags, and in all respects established the identity of the samples to be reported in subsequent testimony. In addition to this the testimony of many local persons living beside or working on the river was introduced at each point for the purpose of procuring their views with reference to the condition of the water in the stream before and after the opening of the drainage canal. As was stated by the counsel for the defendants, these witnesses were not offered as experts on the subject, but merely as laymen who had lived and worked on the river for considerable periods and had had ample opportunity to observe the waters before and since the opening of the drainage canal. The general testimony of these laymen throughout the course of the river was that in physical appearance the water had been greatly improved since the opening of the canal, that previously there had been, in times of low water, a large abundance of aquatic vegetation which frequently gave off foul odors, but that since the opening no such growth had occurred. The testimony of steamboat men and manufacturers with reference to the allged improvement of the water for boiler purposes was also presented, together with certain important testimony concerning the discharge of industrial wastes into the river, which will be reviewed at length in subsequent pages. The report of this testimony covers pages 2890–3498 of the record, representing the period from July 13 to July 24, during which time the commission convened at all important points along the river from St. Louis to Henry, Ill.

C. G. HERGET.

C. G. Herget was called as a witness in behalf of the defendants and testified that he was manager of the Globe distillery, located at Pekin about one-half mile from Illinois River. At this distillery whisky was manufactured, 90 per cent of the raw material being corn and 10 per cent rye and malt. The slop, amounting to 40,000 gallons for each thousand bushels of grain used, was stored in tubs and fed to cattle. At this distillery 4,400 head of cattle were kept in barns located about one-half mile from the river. The slop was fed three times per day to the cattle, about 3 pecks per head at each feeding together with hay or straw or cotton-seed hulls. The refuse from the stables, consisting of uneaten slop and hay and the excreted discharges of the cattle, the latter amounting to about 4 or 5 gallons per animal per day, was washed from the stable into drains and deposited in the river, where in low and medium stages of the stream it formed a sort of island, composed principally of manure, hay, straw, and refuse. During high water this island was cast loose and went floating down the river. (3325–3331.)

PETER CASEY.

Peter Casey testified that from 1895 to 1901 he was manager of four distilleries in Peoria, belonging to what is known as the whisky trust, and from June, 1901, to the date of the testimony, had been manager of the Corning Distilling Company. Between 1895 and 1901 from 12,000 to 20,000 cattle were fed in Peoria in a manner similar to that described in the testimony of C. G. Herget. By 1901 and 1902 the number of cattle fed had dropped to about 8,000. All the waste slop and excrementitious matter from the cattle was discharged into the river. The matter would accumulate along the banks for indefinite periods until high water washed it away, when it would flow down the stream in large islands, one of which was too large to pass between the piers of the Pekin bridge and it was necessary to break it up in order that it might continue on its course.

The witness stated that during recent years there had been a large diminution in the number of cattle fed at Peoria, because of the fact that under the contract it was necessary to feed the cattle for a period of nine months. This made it necessary for them to continue the manufacture of liquor whether there was a demand for the goods or not, and they found that there was a loss in storing high-proof spirits not in demand, which more than compensated for the small amount of profit afforded by the keeping of cattle. This diminution would probably continue because of the growth of the custom of drying the slop by evaporation and selling it for export. (3509–3517, 3540–3544.)

ADOLPH WOOLNER, JR.

Adolph Woolner, jr., for nine years manager of the Atlas distillery, which has a capacity of 7,500 bushels in twenty-four hours, testified that there had been as many as 40,000 head of cattle fed in Peoria at one time, but at the date of testimony about 10,000 were being fed at Peoria and from 5,000 to 8,000 at Pekin. It was the aim to feed about a bushel of distillery waste per animal per day, equivalent, according to the witness, to about 400 pounds. Based on this weight, an animal would consume 98,400 pounds of slop in two hundred and forty days. A steer will gain in eight months an average of 400 pounds in weight. The witness figured that the excretions would amount to 98,000 pounds, or for the entire year 120,000 pounds; therefore the discharge from 40,000 head of cattle would be 2,400,000 tons per year, and that from 10,000 cattle, the number fed at the date of testimony, would be 600,000 tons, so that the amount of pollution from the Peoria cattle sheds will vary between these two limits. (3689–3692.)

ISHAM RANDOLPH.

DIRECT EXAMINATION.

Isham Randolph, chief engineer of the sanitary district of Chicago, was called as a witness on behalf of the defendants, and stated that his engineering experience began in 1868, when he entered the service of the Baltimore and Ohio Railroad as axman. From that time until 1880 he performed engineering services for various railroads, and then became chief engineer of the Chicago and Western Indiana Railroad and the Belt Railway of Chicago, remaining in that position four years. During the next two years he maintained an office for general engineering work in Chicago, and in 1886 entered the service of the Illinois Central Railroad and built the Chicago, Madison and Northern and the Freeport and Dodgeville railroads. In 1888 he returned to private practice and was consulting engineer for various roads until 1893, when he was elected chief engineer of the sanitary district of Chicago, holding this position at the date of the testimony. The duties of this office involve responsibility for all work coming under the term engineering, the preparation of plans and forms of contract, and the enforcement of contracts in connection with construction. (6607–6609.)

The witness then described the condition of Chicago River from 1880 until the opening of the drainage canal, and gave an outline of the sewerage system of Chicago and the effect of its discharge on Chicago River and Lake Michigan. (6609–6613.)

The Illinois and Michigan Canal was then described, the witness stating that it was commenced in 1836 and completed in 1848. It

extends from the south fork of South Branch of Chicago River in a southwesterly direction across the divide between the drainage areas of Lake Michigan and Illinois River to Peru, Ill., a distance of about 96 miles. The original canal had a navigable depth of about 5 feet and a width of about 6 feet. The locks were 110 feet long and 18 feet wide. Since 1884 the "summit level," or the 29-mile stretch of the canal extending from Chicago River to Lockport, had been supplied with water from Chicago River by pumps located at Bridgeport, in the city of Chicago. These pumps were supposed to have a capacity of 60,000 cubic feet per minute, but they did not accomplish this, and in practice the capacity ranged between 45,000 and 50,000 cubic feet. At some seasons of the year the supply of water from Desplaines River was very small, and the canal was almost wholly dependent on the Bridgeport pumps. This water came partly from the stock yards branch and partly through South Branch of Chicago River from Lake Michigan. It flowed through the "summit level" at a velocity of about 1 mile per hour, and was a black liquid of very foul odor. The water in the two pools at Joliet was as bad as that in the canal proper at some seasons of the year, when Desplaines River was low, because of the small amount of dilution. (6613–6616.)

The following statements with reference to the drainage canal were then made by the witness: This canal was the outcome of Chicago's necessities. The conditions affecting her water supply, owing to sewage pollution in Chicago River and the lake, had become steadily worse from the days when the city began to grow. Finally a crisis was reached, and the city council authorized the appointment of an expert commission to determine on a solution of the difficulties. In January, 1886, the commission was appointed, consisting of Rudolph Hering, Benezette Williams, and Samuel J. Artingstall, and as a result of its labors the State legislature in 1889 passed the sanitary district law, under which a board of nine trustees was elected. This board adopted the project for a waterway from Chicago to Lockport, which finally resulted in the construction of the drainage canal. It follows the general location of the old Illinois and Michigan Canal connecting with the west fork of South Branch of Chicago River at Robey street, Chicago, and discharging into Desplaines River at Lockport. (6616–6617.)

The first 7 or 8 miles of the canal is through a clay formation which is easily dredged, and the cross section here is less at present than it will be ultimately. It is 110 feet wide on the bottom, the side slope being 1 foot vertical to 2 feet horizontal, giving a surface width of 19 feet with a minimum depth of water of 22 feet. Beyond this clay stretch a glacial drift was encountered which could not be dredged. In this material the canal was made full size, namely, 202 feet wide on the bottom, with side slopes of 2 feet horizontal to 1 foot vertical,

surface width of water of 290 feet, and a maximum depth of 22 feet. The canal continues of this size for 5.3 miles to Willow Springs, where rock was encountered. From this point to the outlet at Lockport the channel is either wholly in rock or underlain by rock. The width of the canal contracts at this point to 160 feet and the grade is increased from 1 foot in 40,000 feet to 1 foot in 20,000 feet. The length of canal having this cross section is 14.95 miles. Through 7 miles of this distance the sides are cut practically vertical, and wherever rock was not found at the surface walls were built upon rock foundation to a height of 5 feet above Chicago datum. (6617–6618.)

The controlling works at Lockport consist of seven gates of the Stoney type and the Bear Trap dam. The gates have an opening of 32 feet and operate under a maximum pressure of 62,000 pounds. The Bear Trap dam is a structure which can be raised or lowered and is in active use for regulating the flow from the canal, the gates being seldom required. The dam is the largest structure of the kind ever attempted, having a clear waterway of 160 feet with a possible oscillation of 17 feet. The essential parts of the dam were then described by the witness, who stated that it was lowered and the water first turned into Desplaines River January 17, 1900, at 11.05 o'clock a. m. (6618–6621.)

The witness then described the bridges erected across the canal and the improvement of Chicago River and the Desplaines River channel below the foot of the canal at Lockport. The cost of the construction up to the date of the testimony was stated by the witness to be $42,503,168. (6619–6624.)

The original sanitary district included all of Chicago north of Eighty-seventh street and 42 square miles of country lying directly west of that portion of the city, embracing in all 185 square miles. In 1903 the legislature of Illinois passed an act extending the boundaries of the sanitary district by adding 78.6 square miles of territory on the north, known as the north-shore district, and 94.5 square miles on the south, known as the Calumet district. The district now includes all of the city of Chicago, and ultimately the sewage from this entire area will be discharged into the drainage canal, which at that time will be widened so that it will have a discharge capacity of 825,000 cubic feet per minute. (6624–6625.)

The witness then stated that the total population of the sanitary district was 1,942,000. In connection with the sewerage of the southern district it was proposed to reverse the flow of Calumet River by constructing a channel from Little Calumet River near Blue Island southwestward through what is known as Sag Valley to the drainage canal at or near Sag Bridge station on the Chicago and Alton Railroad. This channel will prevent the discharge of Calumet River into Lake Michigan at all times except in excessive floods. On the north it is

proposed to extend North Branch of Chicago River as far as Evanston and make a connection with Lake Michigan at that point. It will be impossible to secure a gravity flow through this channel; therefore pumping works will be erected designed to lift 60,000 cubic feet per minute. (6627–6628.)

The witness then gave the maximum and minimum discharge of the drainage canal during the years 1900–1902, inclusive, together with computations of dilution of sewage and weight and proportion of sewage matter therein. This information is included in Table 43. (6629–6633.)

TABLE 43.—*Discharge and pollution of Chicago drainage canal.*

Year.	Population of Chicago.		Daily water consumption of city (gallons).	
	Total.	Discharging sewage into canal.	Total.	Per capita.
1900	[a] 1,698,575	1,443,789	322,599,630	19
1901	[b] 1,758,000	1,494,300	342,813,449	19
1902	[b] 1,818,000	1,545,300	358,101,710	19

Year.	Discharge of channel at Dam No. 1, from weekly averages (cubic feet per minute).			Quantity of sewage discharged (gallons per day).[c]	Proportion of sewage to mean discharge of canal.	Weight of urine and fecal matter (pounds per day).	Proportio of urine and fecal matter to mean discharge of canal.
	Maximum.	Minimum.	Mean.				
1900	351,068	40,481	233,976	274,209,685	1: 9.2	3,880,183	1:5,4
1901	615,392	197,124	277,153	291,391,432	1:10.2	4,015,931	1:6,21
1902	450,328	244,428	295,527	304,386,454	1:10.4	4,215,494	1:6,31

[a] Census. [b] Estimated. [c] Same as water consumption.

The quantity of sewage stated in above table is determined by taking the amount of water consumed per capita in the city of Chicago, as shown by the reports of the water commissioner for the years mentioned. This sewage is compared with the mean discharge of water from the Illinois and Michigan Canal, the drainage canal, and Desplaines River where they come together at Dam No. 1 in Joliet. The absolute weight of the urine (40 ounces per capita) and fecal matter (3 ounces per capita) given in the table is based on the testimony of Dr. Ravold and statistics gathered from other sources, and is compared with the total weight of water discharged in twenty-four hours from the three sources mentioned. (6634.)

The witness then presented another table differing from the preceding only in the method of determining the amount of sewage per day, which in this table is based on a clause in the report of the commission of hydraulic engineers of St. Louis, dated 1902, reading as follows:

From observations made upon water systems of cities where the quantity of water used is measured, it appears that in large cities the average volumes needed for domes

tic, public, and manufacturing purposes are, respectively, 30 gallons, 5 gallons, and 25 gallons per day for each inhabitant, and that any supply in excess of 60 gallons per day per capita goes to underground leakage and unnecessary waste.

In Table 44 some of the data given in Table 43 are repeated for convenience of reference, and the quantity of sewage is based on a water consumption of 60 gallons per capita per day. (6636–6637.)

TABLE 44.—*Pollution of Chicago drainage canal.*

Year.	Population discharging sewage into the canal.	Discharge of channel at Dam No. 1, from weekly averages (cubic feet per minute).			Quantity of sewage discharged (gallons per day).	Proportion of sewage to mean discharge of canal.	Weight of urine and fecal matter (pounds per day).	Proportion of urine and fecal matter to mean discharge of canal.
		Maximum.	Minimum.	Mean.				
1900	1,443,789	351,068	40,481	233,976	86,627,340	1:29.1	3,880,183	1:5,429
1901	1,494,300	615,392	197,124	277,153	89,658,000	1:33.3	4,015,931	1:6,211
1902	1,545,300	450,328	244,426	295,527	92,718,000	1:34.3	4,215,494	1:6,310

The witness then presented Table 45, containing statistics of the population of Chicago. (6641.)

TABLE 45.—*Population of Chicago, 1840–1903.*

1840	4,470	1890	1,099,850
1850	29,963	1900	1,698,575
1860	112,172	1901	1,758,000
1870	298,977	1902	1,818,000
1880	503,185	1903	1,878,000

The figures for 1840 to 1900, inclusive, are from the census reports; those for 1901 to 1903, inclusive, are estimated. The proportion of the population discharging into the drainage canal was stated to be 87 per cent by the Federal census of 1890; 84 per cent by the school census of 1898, and 85 per cent by the present estimates, as shown in Table 43.

The amount of sewage discharged per day was reduced to terms of gallons and cubic feet per minute, as follows:

TABLE 46.—*Sewage discharged into drainage canal.*

Year.	Gallons per day.	Gallons per minute.	Cubic feet per minute.
1900	274,209,685	190,423	25,458
1901	291,391,432	202,355	27,053
1902	304,386,454	211,379	28,259

The witness presented another table showing the amount of excreta of 100,000 persons per year, and subsequently discussed the same with reference to the drainage canal and the dilution therein. (6644–6645.)

He then presented Table 47, showing the number of inhabitants and estimated pollution of Illinois River basin. (6646.)

TABLE 47.—*Pollution of Illinois River.*

Drainage basin.	Area (square miles).	Population (census of 1900).	Urban population (towns of 1,000 and over), 1900.	Estimated wa Gallons per da	
				Per capita.	Tota
Desplaines River	1,758	124,855	70,748	99.3	7,025,
Dupage River		21,704	6,851	23.1	158,
Kankakee River	5,302	192,226	44,681	53.2	2,377,
Fox River	2,697	175,353	81,743	47.3	3,866,
Vermilion River	1,413	68,601	27,631	70.1	1,937,
Mackinaw River	1,182	47,296	10,924	37.1	405,
Spoon River	1,905	81,782	28,519	40	1,141,
Sangamon River	5,592	303,096	133,632	91.4	11,215,
Crooked Creek	1,286	54,574	14,344	13.9	199,
McKees Creek		16,461	5,624	32	180,
Macoupin Creek	1,000	46,362	15,778	32	505,
Illinois River (directly)		379,077	177,189	65.5	11,606,
Peoria industries					15,000,
Total		1,511,387	617,664	65.7	55,614,

The discharge of the Illinois is estimated as follows:

Discharge of Illinois River.

Discharge of Illinois River at Kampsville October 20, 1891 (according t
United States engineers)
Less discharge of Illinois and Michigan Canal

Natural discharge of river at Kampsville
Add for basin of Macoupin Creek

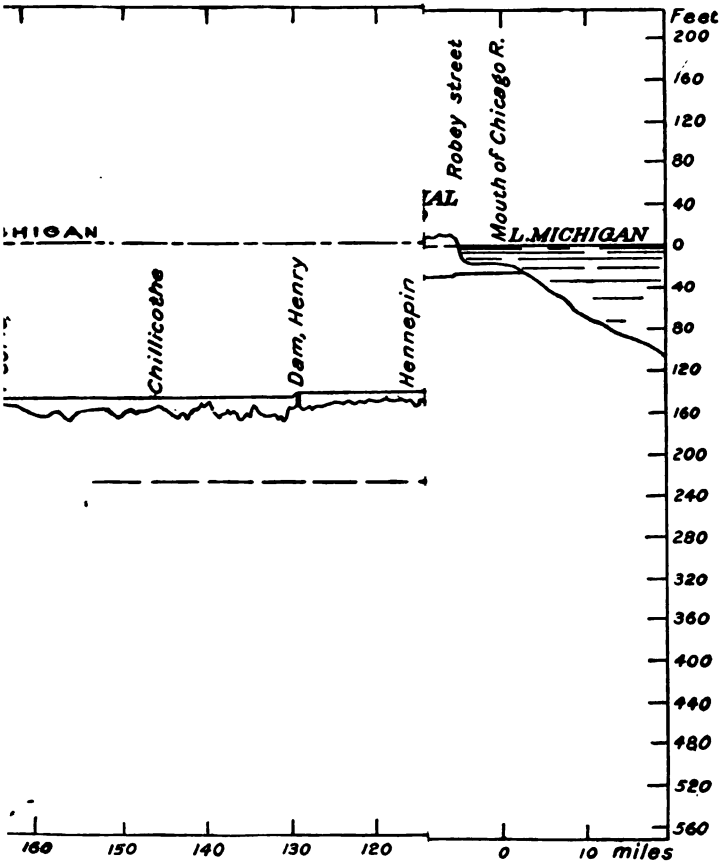
Natural discharge of Illinois River

The sewage produced by the urban population, based o
supply as shown in table, is 85.72 cubic feet per second, o
reduced to a basis of 60 gallons per capita per day, 57.19 cu
per second. Dividing 1,000, the natural discharge of the r
57.19, the amount of sewage, gives a ratio of pollution of 1 t
as against the drainage-canal pollution of 1 to 34.3.

After discussing the items in the above table the witness
that his conclusion was that the ratio of pollution in Illinoi
due to the urban and rural population naturally draining into it
exclusive of all sewage coming from Chicago, was greater th
present ratio, resulting from the combination of this natural p
with the discharge from the drainage canal. The discharge fr
canal being omitted, the proportion of pollution to diluting w
1 to 17.48, whereas the proportion in the canal (see Table 44)
34.3. (6647–6648.)

The witness then described and discussed the physical chara
tics of Desplaines and Illinois rivers throughout the length o
channels. (6650–6651.)

He then presented a map showing the population of the dr
areas of Illinois, Mississippi, and Missouri rivers above St. Lou
stated that the population of the Illinois basin, exclusive of Ch
was 599,751, and with Chicago included, 2,298,326; of the Missi



IOIS RIVER, AND MISSISSIPPI RIVER

basin above Grafton, 1,839,586, and of the Missouri basin above the mouth of the river, 1,650,594, giving a total population above St. Louis of 5,788,506. (6653–6655.)

The witness then entered into a detailed discussion of river flow and gaging, covering all the streams above mentioned. (6655–6667.) He introduced into evidence a profile of the entire waterway from Lake Michigan to Cairo, Ill., which is reproduced herewith as Pl. II.

The witness then described some float measurements made for determining the velocity of the river from Chicago to St. Louis. Wooden balls were put in the river at Lake street and allowed to float down to Robey street, a man following in a boat to ascertain the time required in transit. From Robey street to Lockport the velocity was computed from the known volume and cross section. From Lockport to St. Louis floats were used of the same general character as those described in the testimony of Mr. Van Ornum. These floats were followed throughout the distance, part of the time on shore, because a boat could not be taken through the rapids. They were kept going night and day except when accidents of any kind stopped the work; on such occasions they were taken out and the time noted. Through the rapids wooden balls were substituted for the floats. The river at the time of this measurement was at a fairly full stage, somewhat above that which might be called the mean stage, but not anything like a maximum flood flow. The results are contained in Table 48. (6667–6670.)

TABLE 48.—*Results of float measurements from Lake Michigan to St. Louis.*

	Interval.			Corrected interval.			Total time.			
	Days.	*h.*	*m.*	*Days.*	*h.*	*m.*	*Days.*	*h.*	*m.*	*Days.*
Lake street to Robey street	0	5	30	0	6	52	0	6	52	0.3
Summit		5	42		5	42		12	32	.5
Willow Springs		7	22		7	22		19	54	.8
Controlling works		18	54		18	54	1	14	48	1.6
Joliet		1	58		2	28	1	17	16	1.7
Lake Joliet		1	24		1	45	1	19	1	1.8
Through Lake Joliet		2	15		2	49	1	21	50	1.9
Kankakee cut-off		3	40		4	35	2	2	25	2.1
Morris		8	11		10	14	2	12	39	2.5
Seneca		7	45		9	41	2	22	20	2.95
Marseilles		6	45		8	26	3	6	46	3.3
Ottawa		3	25		4	16	3	11	2	3.45
Utica		5	55		7	24	3	18	26	3.75
Peru		5	30		6	52	4	1	18	4.05
Henry dam	1	0	31	1	6	39	5	7	57	5.35
Lacon		8	48		11	0	5	18	57	5.8
Peoria	2	21	15	3	14	34	9	9	31	9.4
Pekin		10	2		12	32	9	22	3	9.9
Copperas Creek dam		13	43		17	9	10	15	12	10.65
Havana		14	31		18	9	11	9	21	11.4
Louderbach		15	36		18	43	12	4	4	12.15
Frederick		10	0		12	30	12	16	34	12.7
Beardstown		1	58		2	22	12	18	56	12.8
Lagrange dam		10	24		13	0	13	7	56	13.35
Griggsville		12	53		16	6	14	0	2	14
Pearl		16	52		21	5	14	21	7	14.9
Kampsville dam		12	52		16	5	14	13	12	15.55
Hardin		12	44		15	55	16	5	7	16.2
Hadleys		10	24		13	0	16	18	7	16.75
Grafton		17	47		22	14	17	16	21	17.7
Alton		7	40		9	35	18	1	56	18.1
Merchants' Bridge		6	51		8	34	18	10	30	18.45
Eads Bridge			58		1	10	18	11	40	18.5

Counsel for the defense then directed the attention of the wi to various reports made by the health commissioner of the city Louis, together with the resolutions adopted by the city counci a draft of a bill introduced in Congress, all relating to the mat pollution of St. Louis water supply by the effluent from Illinois (6672–6688.)

CROSS-EXAMINATION.

The cross-examination of this witness brought out no new fa opinions.

RUDOLPH HERING.

DIRECT EXAMINATION.

Rudolph Hering, a witness called in behalf of the defen qualified as an expert by making the following statements: He a member of the firm of hydraulic and sanitary engineers compo Rudolph Hering and George W. Fuller. He took the course in engineering at Dresden, Germany, in 1867, and after returni America began his engineering work at Brooklyn, on Prospect and then went to Philadelphia, on Fairmont Park. From 18 1880 he was first assistant engineer in charge of bridges and s in Philadelphia, and in the latter year was commissioned by national board of health to examine and report on European s age systems. Since that time he had been consulting enginee the waterworks and sewerage systems of many cities, inclu Philadelphia, Cleveland, Chicago, New York, Baltimore, New Orl and Washington. (6975–6978.)

The witness stated that in March, 1886, he was engaged as engineer of the drainage and water-supply commission of the ci Chicago, and in that capacity made investigations with referen obtaining pure water and scientific drainage for the city. A liminary report was made in January, 1887, giving the general clusions which had been reached up to that time. The witness read a part of this report, which appears in the record of testim pages 6980 to 6990. Commenting on the facts and condition which the conclusions were based, the witness stated that the pr sition was somewhat novel, and that in order to reach a safe conclu in regard to the size and other conditions for the proposed drai canal it was necessary for him to study all the facts bearing on subject which could be ascertained both in Europe and Ame He found at the outset that the problem of water pollution distinct from that of setting up a standard of purity based on minimum allowable proportion of sewage. If the water is to be for drinking, it should evidently be considered in a different light

if mere inoffensiveness were required. The question was very different at that time from what it is at the present day, and the best information available was afforded by the observations of Dr. John Rauch, secretary of the State board of health of Illinois, who, in making investigations on the gradual change of the water of the old Illinois and Michigan canal after it entered Illinois River, had fixed a unit of flow of water equal to 180 cubic feet per minute for every thousand persons draining into the river at Chicago as sufficient to obviate any substantial injury to the water. From the results of other investigations made by the witness, he concluded that the Chicago drainage canal should have a sufficient capacity to carry water at the rate of 240 cubic feet per minute for each thousand persons. With reference to the subject of dilution in the above connection, the witness stated that if the foul water of a community is to enter a stream used for drinking purposes, it is imperative to purify either the water or the sewage, but if such stream is not used for water supply so complete a purification may not be required, as it is then necessary merely to prevent a nuisance. It is impossible to prevent all disease germs from going into a watercourse. The rain falling on the streets, fields, and forests and discharging into the streams must carry along the dust of the air and of the ground and myriads of bacteria, including disease germs. Parts of the intestinal discharges of animals, birds, and insects must also be washed in, and altogether much injurious matter is carried into watercourses by the rain; therefore, inasmuch as it is impossible to prevent river pollution, all surface-water supplies must be purified. (6990–6993.)

After the report of the drainage and water-supply commission was published, the Massachusetts State board of health made some investigations, and from this information the witness had compiled Table 49, which he then presented. (6995.)

TABLE 49.—*Calculated composition of sewage of different degrees of dilution in a running stream.*

Amount of flowing water.		Composition of sewage (parts per 100,000).				Remarks.
Cubic feet per second per 1,000 persons.	Gallons per capita per day.	Ammonia. Free.	Ammonia. Albuminoid.	Dissolved solids.	Chlorine.	
0.062	40	4.50	0.90	65.4	12.6	Dilution is offensive.
.077	50	3.60	.72	52.3	10.1	
.093	60	3.00	.60	45.3	8.4	
.108	70	2.57	.52	37.4	7.2	
.124	80	2.25	.45	32.7	6.3	
.140	90	2.00	.40	29.1	5.6	
.155	100	1.80	.36	26.2	5.0	
.186	120	1.50	.30	21.8	4.2	
.232	150	1.20	.24	17.4	3.4	
.310	200	.90	.18	13.1	2.5	
.388	250	.72	.14	10.5	2.0	
.465	300	.60	.12	8.7	1.7	
.5	323	.5580	.114	8.10	1.56	
1	646	.2790	.0557	4.05	.78	
1.5	969	.1860	.0371	2.70	.52	
2	1,292	.1395	.0278	2.02	.39	
2.5	1,615	.1116	.0223	1.62	.31	
3	1,938	.0930	.0186	1.35	.26	
4	2,584	.0697	.0139	1.01	.19	
5	3,230	.0558	.0111	.81	.16	
6	3,876	.0465	.0093	.67	.13	
7	5,522	.0399	.0080	.58	.11	
8	5,168	.0349	.0070	.51	.10	Dilution is not offensive.
9	5,814	.0310	.0062	.45	.09	
10	9,463	.0279	.0056	.40	.08	
15	9,694	.0186	.0037	.27	.05	
20	12,926	.0139	.0028	.20	.04	
30	19,389	.0093	.0019	.13	.03	
40	25,852	.0070	.0014	.10	.02	
50	32,315	.0056	.0011	.08	.02	
100	64,630	.0028	.0006	.04	.01	

In discussing the above table, the witness stated that in applyin the factors it is necessary to take into consideration each specifi case, because no single rule applies to the great differences foun in streams. He called attention to the two lines drawn across th table. Above the upper line conditions are indicated where the dilu tion is in all cases offensive; below the lower line the dilutions expresse have never been found to give offense; between the two lines the con ditions are debatable, and it is the duty of the engineer to select betwee these limits that dilution that conforms to local conditions. In con nection with the drainage canal he had adopted the standard of cubic feet per second per thousand persons, because in the state o knowledge at that time he did not feel justified in recommending a les dilution. Subsequently, the amount was reduced to 3.33 feet pe thousand persons, and on that basis the canal was constructed. (6996.

The witness then presented Table 50, based on population and flo of the drainage canal, showing approximate dilutions. (6997.)

TABLE 50.—*Flow of drainage canal.*

Year.	Population discharging sewage into the canal.	Maximum.		Minimum.		Mean.	
		Cubic feet, per minute, weekly average.	Cubic feet per second per 1,000 inhabitants.	Cubic feet per minute, weekly average.	Cubic feet per second per 1,000 inhabitants.	Cubic feet per minute, weekly average.	Cubic feet per second per 1,000 inhabitants.
1900	1,443,789	351,088	4.05	40,481	0.46	233,976	2.70
1901	1,494,300	615,392	6.86	197,124	2.19	277,153	3.09
1902	1,545,300	450,328	4.85	244,426	2.63	295,527	3.18

The witness then stated that in figuring out the matter of dilution he had considered first the habitations and cities which lie along the drainage canal and Desplaines and Illinois rivers, in front of which the water was to pass. As the dilution would become greater by the inpourings of the tributaries of these rivers, it was to be presumed that what would be a satisfactory dilution in the canal would be still more satisfactory with the greater dilution below. The advances made in the subject of sewage disposal since his recommendations had not changed his views concerning the Chicago problem, and were he to make another recommendation it would be practically the same as that which had been carried out. (6998–7000.)

The witness then introduced a chart, entitled "Schematic representation of the self-purification of the waters of Missouri, Mississippi, and Illinois rivers, between points indicated, based on the length of life of the typhoid bacillus as fixed by experiments made under the direction of Hiram F. Mills." This chart contained profiles of Missouri, Mississippi, and Illinois rivers above St. Louis, and the witness pointed out that the Missouri is the steepest of the three, falling from Omaha, at an elevation of 960 feet, to St. Louis, at an elevation of 380 feet above sea level; the Mississippi falls from Minneapolis, at an elevation of 794 feet, to 380 feet at St. Louis; the Illinois and the drainage canal fall from an elevation of 578 feet at Lake Michigan to 400 feet at Grafton and finally to 380 feet at St. Louis. The distance from Omaha or Minneapolis to St. Louis by water is about 680 miles and that from Lake Michigan to St. Louis by water is about 400 miles. Therefore it will be seen that the velocity of Missouri River is the greatest of the three and that the Illinois is the flattest and has the lowest velocity. The chart also presented certain deductions made on the basis indicated in the title, namely, the longevity of the typhoid bacillus as determined by Hiram F. Mills. In Mills's report it is attempted to prove whether typhoid germs would survive in Merrimac River water at the low temperature of the month of November long enough to pass from the Lowell sewers to the service pipes in Lawrence. A series of experiments were made by the Massachusetts State board of health by inoculating water from the service pipe with typhoid-fever germs, keeping the water in a bottle surrounded by ice,

and each day taking out 1 c. c. and determining the number of typhoid organisms. The number continually decreased, but some survived about twenty-four days, as follows:

Number of typhoid-fever germs surviving in water at about freezing point.

First day	6,120	Fifteenth day	100
Fifth day	3,100	Twentieth day	17
Tenth day	490	Twenty-fifth day	0

The ordinates of the curves presented on the chart represented the relative number of typhoid bacilli still living at the various points indicated, it being assumed in the absence of other information that the number of germs is directly proportional to the population. So far as the average flow of water is concerned, Chicago is about eighteen and one-half days distant from St. Louis, Kansas City six and three-fourths days, Omaha eleven and six-tenths days, and Minneapolis and St. Paul are about fifteen days. The conclusions to be drawn from the chart are that the relative proportions of typhoid bacilli arriving at St. Louis from populations on Illinois, Missouri, and Mississippi rivers, below Chicago, Omaha, and Minneapolis, are about as 13 to 96 to 107, respectively. These figures are merely the proportions. They indicate the relative frequency of the still virulent typhoid bacilli arriving at St. Louis from various cities on the three rivers, based on the population of the cities and the determinations made by Mills as above outlined. (7002–7003.)

The witness expressed the opinion that the waters of Illinois River above Grafton, of Mississippi River at the same point, and of Missouri River above its mouth were not fit for domestic consumption in the raw state either before or after the opening of the Chicago drainage canal, and that the discharge of the drainage canal into Illinois River makes practically no difference in the method of construction or cost of operation of a suitable filtration system for St. Louis. Under the assumption that the water was to be taken from the present intake at Chain of Rocks, he added that in providing for such a filtration system he would first procure some satisfactory evidence as to the turbidity of the water, because that affects the manner of treatment more than anything else, and after that he would consider the pollution of the river and the number and kind of bacteria contained in the water, because the treatment that would remove the suspended matter from the water of Mississippi River at St. Louis would also remove the greater part of the dangerous bacteria. He stated that he would give no consideration to the sewage from Chicago, because it would be too small a factor in the problem to materially affect any recommendation; moreover, the operation of such a filter would not require a higher degree of skill or more expensive attendance under the present conditions than it would before the opening of the canal. (7000–7007.)

CROSS-EXAMINATION.

The witness reviewed the suggested measures presented in his report to the city in 1886, by which purification of the Chicago water supply could be brought about. Besides the construction of the canal, there was a proposition to remove the sewage to lands adjacent to the city and dispose of it by broad irrigation, and another to continue the discharge into Lake Michigan under much improved conditions, namely, that the intake for the water supply should be located as far as practicable from the point of sewage discharge and that the sewage should be treated by screening so as to deprive it of the grosser pollution and in that way make it more unobjectionable and more rapidly dispersed. He was of the opinion, however, that this was not a satisfactory method. He stated that discharge directly into the lake rather than by way of Chicago River was preferable because the river was loaded with an accumulation of organic matter, collected during those times when the flow was very slight, and whenever there was heavy rainfall all this accumulated matter would be carried out to one of the water intakes, whereas in the method of lake dilution there would be a continuous discharge and no sudden rush of an accumulation of filthy matter, so that its effects would cover smaller areas. He noted on one occasion, for example, the effect of such a sudden discharge. Shortly after a freshet he followed the river water out into the lake until dark and computed that within an hour's time, approximately, the water would reach the intake crib and then go to the pumping station and be delivered to the residents. He therefore returned to his home, which was located close to the pumping station, and observed the condition of the water in the bathroom during the entire night. Early in the morning the water running into the bath tub, which had been comparatively clear and pure, became foul smelling. (7021–7023.)

The possible pollution of the Chicago water supply from the sewers of Milwaukee was discussed by the witness, who stated that the distance was about 90 miles and that, according to observations, the velocity of the currents in the lake sometimes reached 2 or 3 feet per second, though usually less. In response to requests of the cross-examiner he estimated that, with a current from the north having a velocity of 2 feet per second, it would require seventy hours, or about three days, for the Milwaukee sewage to reach the Chicago intake, and he then stated that the assumption was false and that no Milwaukee sewage could reach the intakes, because the water near the lake shore does not move in a parallel direction to the shore, but there are cycloidal motions and the water passing the Milwaukee sewage outlet would be so dispersed, even though the winds were favorable, that that particular water would not reach Chicago for weeks and possibly months. (7025–7026.)

JACOB A. HARMAN.

Jacob A. Harman, called as a witness in behalf of the defendants, outlined an extensive engineering experience and stated that for the five years previous he had been consulting engineer to the State board of health of Illinois. The purport of the testimony was to show the flow of Illinois River and its various tributaries and to discuss the same. The full testimony occupies pages 6847 to 6868, and the most comprehensive results are contained in Table 51.

The witness then stated that he had made an investigation of the sewerage system of St. Charles, Mo., March 10 and 11, 1903. This city is located on the left bank of Missouri River at a distance overland from the business district of St. Louis of about 16 miles. All the sewers of the city drain into the river. The land rises abruptly from the river bank, and, at a distance of three or four blocks back therefrom, the elevation is 100 feet or more above the stream. The drainage of all the business district and nearly all of the residence district therefore flows directly into the river. A part of the residence district drains into the Mississippi. St. Charles is not provided with a complete sewer system. There are four public sewers, ranging from three or four blocks to eight blocks in length, and many private sewers from hotels and business houses leading direct to the river.

It was brought out on cross-examination that although less than one-third of the area of St. Charles is sewered a somewhat larger percentage of the population is connected with sewers. (6863–6864, 6867.)

JOHN H. LONG.

DIRECT EXAMINATION.

John H. Long, called as a witness in behalf of the defendants, qualified by stating that he was a teacher of chemistry at Northwestern University, Chicago, and had held such position for twenty-two years. Prior to that he had taught in Wesleyan University, at Middletown, Conn., and for seven years previous had been engaged in the study of chemistry. He graduated from the University of Kansas in 1887, and for three years thereafter had studied in the German universities at Tübingen, Würzburg, and Breslau. He further stated that he was a member of several American and foreign scientific societies, the president of the American Chemical Society, and the author of a number of works on chemistry. His studies had been confined mainly to the lines of sanitary and physiological chemistry. Between 1885 and 1890 he was chemist for the board of health of Chicago and since 1885 had been chemist for the Illinois State board of health. (3984–3986.)

TABLE 51. *Discharge of Illinois River as affected by its tributaries, based on discharge measurements at Peoria and ratios of drainage areas.* (6861.)

Subdivisions of Illinois River drainage basin.	Approximate distance from Lockport (miles).	Ratio of drainage area to that above Peoria.	Sum of ratios of drainage areas.	Discharge (cubic feet per second).[a] For Illinois River exclusive of Chicago River. Average 1890 to 1899, inclusive. Low.	Ordinary.	High.	Average 1900 to 1903, inclusive. Low.	Ordinary.	High.	For Illinois River including Chicago River. Average 1890 to 1899, inclusive. Low.	Ordinary.	High.	Average 1900 to 1903, inclusive. Low.	Ordinary.	High.
Chicago River to Lockport	0									600	600	600	3,801	4,162	4,162
Desplaines River to Dupage River	15	0.0656		60	214	1,141	178	407	1,753	660	814	1,741	3,979	4,569	5,915
Desplaines River to Kankakee River		.1027	0.1027	94	334	1,788	280	636	2,743	694	934	2,388	4,081	4,798	6,905
Kankakee River	19.5	.3813	.4840	444	1,577	8,424	1,328	3,000	12,934	1,044	2,177	9,024	5,129	7,162	17,096
Small streams to Fox River		.0735	.5575	513	1,816	9,703	1,530	3,455	14,890	1,113	2,416	10,303	5,331	7,617	19,061
Fox River	52.6	.2003	.7578	697	2,360	13,180	2,080	4,693	20,252	1,297	2,969	13,780	5,881	8,855	24,414
Small streams to Vermilion River		.0101	.7679	706	2,502	13,365	2,108	4,759	20,521	1,306	3,102	13,965	5,909	8,921	24,683
Vermilion River	62.1	.0977	.8656	796	2,820	15,066	2,376	5,364	23,132	1,396	3,420	15,666	6,177	9,526	27,294
Small streams to Peoria		.1333													
At Peoria	131.6		1.0000	920	3,258	17,406	2,745	6,198	26,724	1,520	3,858	18,006	6,546	10,360	30,886
Small streams to Mackinaw River		.0261	1.0261	954	3,343	17,859	2,816	6,360	27,421	1,554	3,943	18,459	6,617	10,522	31,583
Mackinaw River	140.5	.0903	1.1164	1,026	3,637	19,533	3,065	6,920	29,834	1,626	4,237	20,133	6,866	11,082	33,996
Small streams to Spoon River		.0400	1.1564	1,064	3,767	20,128	3,186	7,167	30,903	1,664	4,367	20,728	6,987	11,329	35,065
Spoon River	171.1	.1379	1.2943	1,191	4,216	22,527	3,552	8,021	34,589	1,791	4,816	23,127	7,353	12,183	38,751
Small streams to Sangamon		.0104	1.3047	1,200	4,250	22,708	3,581	8,085	34,866	1,800	4,850	23,308	7,382	12,247	39,026
Sangamon River	193.6	.4206	1.7253	1,587	5,621	30,030	4,735	10,692	46,107	2,187	6,221	30,639	8,536	14,854	50,269
Small streams to Crooked Creek		.0134	1.7387	1,599	5,665	30,262	4,771	10,776	46,465	2,199	6,265	30,862	8,572	14,938	50,627
Crooked Creek	207.8	.1027	1.8414	1,694	5,998	32,051	5,054	11,412	49,209	2,294	6,598	32,651	8,855	15,574	53,371
Small streams to McKees Creek		.0214	1.8628	1,714	6,067	32,424	5,112	11,524	49,780	2,314	6,667	33,024	8,913	15,686	53,942
McKees Creek	225.2	.0350	1.8978	1,745	6,181	32,933	5,209	11,761	50,716	2,345	6,781	33,533	9,010	15,923	54,878
Small streams to Macoupin Creek		.0879	1.9857	1,827	6,468	34,561	5,448	12,305	53,065	2,427	7,068	35,161	9,249	16,467	57,227
Macoupin Creek	268.1	.0738	2.0595	1,894	6,710	35,846	5,653	12,763	53,037	2,494	7,310	36,446	9,454	16,925	59,199
Small streams to Mississippi River		.0114													
Junction of Illinois River with Mississippi River	283.5		2.0709	1,904	6,747	36,045	5,681	12,834	55,341	2,504	7,347	36,645	9,482	16,996	59,503

[a] "Low"—average for low quarter; "high"—average for high quarter.

It is apparent that the witness had had a long and intimate experience with the general problems connected with the water supply and sewage disposal of the city of Chicage and the Illinois River basin, as his testimony contains a large amount of historical matter in connection with the development of both these improvements. (3986–3995.)

The investigations of the witness, begun in 1885, included the examination of a great many samples of water from the Chicago avenue, Evanston, Lakeview, and Hyde Park tunnels. (3995.)

The next examinations, in 1886, comprised a study of samples of the river and canal water taken weekly from Bridgeport, Lockport, Joliet, Ottawa, La Salle, and Peoria. Another series of examinations of water taken from the same points began in December, 1886, and was continued through the cold months into March, 1887. The results of these examinations were published in the reports of the State board of health for that period. (3996–3997.)

The next investigations were made two years later, beginning May 1, 1888, and extending to about the middle of November. The sampling points in this series were as follows, including, besides those above mentioned, several points below Peoria to the mouth of the river at Grafton: Bridgeport, Lockport, Joliet, Morris, Ottawa, La Salle, Henry, Peoria, Pekin, mouth of Copperas Creek, Havana, Beardstown, Pearl, and Grafton. During the same investigation a number of samples were taken from Dupage, Kankakee, Fox, Vermilion, Little Vermilion, and Sangamon rivers, tributaries of the Illinois. All these samples were taken from appropriate points above the confluence of each stream with Illinois River. These results were published in the preliminary report of the State board of health for 1889. The witness stated that he wished to explain this preliminary report, which had been extensively quoted by the witnesses for the plaintiff and attracted considerable attention at the time it was issued. It was brought out by the secretary of the State board of health for the use of some committee of the State legislature in a very great hurry. The work of printing the report was begun but a few days after the completion of the last analysis, so that the work must be regarded as only of a preliminary character, and while the details were complete the text and explanatory matter was comparatively meager. The full report, which was subsequently put into the hands of the secretary, was lost in some manner and never printed. The results in the preliminary report are essentially correct so far as they could be made so in the extremely limited time for preparation, and the averages of results are practically correct. (3996–3999.)

The next investigation was made of the water in the neighborhood of the Bridgeport pumps, Chicago, in the winter of 1890 and 1891, the object being to show the relative amounts of pollution coming from

the stock yards and from the rest of the city. Samples were taken from the large sewers leading from the stock yards, and from the so-called Brennock sewer and the Ashland avenue, Halstead street, and Thirty-ninth street sewers, all representing the bulk of the sewage aside from that contributed by the stock yards. (3999–4000.)

The witness was then requested to take each series of investigations and describe fully how the samples were collected and delivered and where the analyses were made, stating in reply that those for the series of 1886 were collected by Doctor Rauch, secretary of the State board of health, through the health officers of various towns, and sent in jugs packed in boxes to the laboratory of the Northwestern University Medical School. The later samples were collected in the same way and sent to the Northwestern University School of Pharmacy. He then proceeded to describe the methods used in making and interpreting the analyses and the importance of the various determinations. (4000–4010, 4026–4027.)

The witness then recited the results of his examinations of the water of the Illinois and Michigan Canal and Desplaines and Illinois rivers, made in 1886. These results are given as averages of twelve samples taken at each of the sampling points and are included in Table 52. (4028–4029.)

TABLE 52.—*Average results of partial analyses of water from Illinois and Michigan Canal and Desplaines and Illinois rivers during the summer of 1886.*

[Parts per million.]

Place.	Distance below Bridgeport (miles).	Albuminoid ammonia.	Free ammonia.	Oxygen consumed.
Bridgeport	0	1.633	26.563	26.20
Lockport	29	.753	12.733	11.01
Joliet	33	.432	9.426	9.34
Ottawa	81	.243	.413	5.30
Peoria	159	.194	.027	4.81

In interpreting the results set forth in the above table, the witness stated that the analyses show beyond question a marked destruction of organic matter in the water flowing between Bridgeport and Peoria. In the opinion of the witness, this destruction was due mainly to bacterial oxidation. The water at Peoria was practically potable and actually used by a large number of people.

The results of the investigations in the winter of 1886–87 are set forth in Table 53. (4030–4031.)

TABLE 53.—*Average results of partial analyses of water from Illinois and Michigan Canal and Desplaines and Illinois rivers during the winter of 1886–87.*

[Parts per million.]

Place.	Distance below Bridgeport (miles).	Albuminoid ammonia.	Free ammonia.	Oxygen consumed.
Bridgeport	0	3.7	9.7	22.4
Joliet	33	2.2	6.5	11.3
Ottawa	81	.75	4.7	9.0
Peoria	159	.43	1.7	6.4

Referring to the above results, the witness stated that there was a very considerable destruction of organic matter in the water as it flows from Bridgeport to Peoria, but much less than that shown in Table 52, indicating unmistakably that oxidation is much less marked in cold than in warm weather.

The witness then presented a summary of the results of examinations made from May to October, 1888, and during 1889. (4031–4040.)

TABLE 54.—*Analyses of water from Illinois and Desplaines rivers at designated points May to October, 1888, and during 1889.*

[Parts per million.]

	Number of analyses.		Total solids.		Suspended matter.		Albuminoid ammonia.		Free ammonia.	
	1888.	1889.	1888.	1889.	1888.	1889.	1888.	1889.	1888.	1889.
Bridgeport	29	9	471.2	376.6	129.2	27.2	2.558	2.806	12.253	8.92
Lockport	24	8	431.2	408.6	69.80	24.6	1.990	2.489	10.882	8.14
Joliet	26	8	442.7	432.8	107.9	55.5	1.681	2.666	8.932	8.48
Morris	24	8	355.9	325.2	30.85	29.1	.707	1.587	4.107	4.71
La Salle	23	9	345.7	417.6	50.30	93.8	.526	.637	.636	1.45
Henry	19	5	306.0	316.0	27.50	30.9	.481	.404	.467	1.05
Peoria	19	6	329.75	331.0	54.27	26.9	.522	.549	.210	1.63
Pekin	16	6	353.0	352.0	84.3	43.5	.650	1.015	.645	1.59
Havana	25	9	301.78	354.4	45.4	.8	.430	.585	.342	1.07
Beardstown	24	6	390.0	317.8	84.7	56.3	.380	.357	.202	.76
Grafton	12	9	301.6	410.8	50.3	44.6	.483	.722	.095	.87
Alton	15	8	278.6	309.9	75.2	61.3	.356	.396	.166	.42

	Nitrates.		Oxygen consumed.		Chlorine.		Hardness as $CaCO_3$	
	1888.	1889.	1888.	1889.	1888.	1889.	1888.	1889.
Bridgeport	0	0	23.113	26.502	46.811	62.934	201.3	.....
Lockport	0	0	16.230	22.820	46.120	56.083	207.7	.....
Joliet	0	0	14.301	21.717	43.658	57.17	216.8	.....
Morris	.380	0	10.92	10.696	32.149	28.748	214.8	.....
La Salle	1.037	.942	8.558	8.582	19.717	13.105	211.7	.....
Henry	.683	.962	8.657	8.626	17.660	11.691	202.4	.....
Peoria	.892	.510	9.769	9.611	12.358	12.860	199.7	.....
Pekin	.795	1.259	9.410	13.358	16.152	11.792	204.6	.....
Havana	.731	.414	8.142	9.234	11.583	9.277	204.2	.....
Beardstown	.620	.996	7.354	5.505	7.524	6.933	204.9	.....
Grafton	.582	.087	7.300	9.818	9.205	7.523	242.4	.....
Alton	.....	.317	7.356	7.562	4.083	5.834	169.4	.....

These results, according to the witness, show a purification of the river between Bridgeport and Grafton. The diminution in organic matter is due to two important factors—the dilution of the stream by water from various tributaries and the destruction of organic matters

by oxidation, that term being used in a broad sense. Oxidation is much more important than dilution, as indicated by the change in chlorines, a condition being finally reached in which the organic matter is not greater in amount than in the unpolluted streams commonly found in that part of the country.

The witness then presented the results of the examination of samples of water taken from important tributaries of Illinois River at weekly intervals from May 4 to September 21, 1888. The means of these results are given in Table 55. (4040–4071.)

TABLE 55.—*Average results of analyses of weekly samples of water from Illinois River tributaries at designated points and dates in 1888.*

[Parts per million.]

Tributary.	Place of collection.	Period included in average.	Number of analyses.	Total solids.	Suspended solids.	Nitrogen as— Albuminoid ammonia.	Nitrogen as— Free ammonia.	Nitrogen as— Nitrates.	Oxygen consumed.	Chlorine.	Hardness.
Dupage River	Channahon	Aug. 10–Sept. 21	7	294.7	14.1	0.346	0.417	0.307	4.743	5.786	244.8
Kankakee River	Wilmington	May 4–Sept. 21	19	251.4	35.6	.585	.114	.094	12.661	1.015	164.1
Fox River	Ottawa	May 14–Sept. 17	18	330.3	46.3	.463	.278	.027	7.066	4.974	242.1
Vermilion River.	La Salle	May 7–July 16	7	450.6	87.8	.341	.049	3.348	6.914	5.461	255.8
Little Vermilion River.	do	do	7	375.1	30.8	.411	.180	.362	7.15	5.664	210.2
Sangamon River.	Chandlerville	July 10–Sept. 3	8	317.8	70.7	.285	.053	.755	5.480	3.609	212.0

In explaining the mean of the determinations of samples from Dupage River the witness stated that the average given includes only the last seven determinations—namely, from August 10 to September 21—because there was some uncertainty about the point of collection of the samples taken prior to August 10, and therefore he had omitted them in making up the summary. Inasmuch as the results of the individual analyses are not given for Dupage River in this review, it should be stated that the samples taken previous to August 10 indicated a far higher degree of pollution than those which are actually included in the mean, and if all were included—that is, if the average was made from the results of the 21 analyses reported—the amounts would be greatly increased. The suspended solids, albuminoid ammonia, and oxygen consumed would be increased about 25 per cent, the nitrates 100 per cent, the chlorine 400 per cent, and the free ammonia 600 per cent. The mean actually used by the witness does not include the spring and early summer samples, and unless this is understood errors may arise in the comparison of the mean for Dupage River with that of the other tributaries. In order that there may be no errors from such a comparison, a statement of the period during which the samples were taken to make up each average is included in the table.

The witness then stated that a comparison of the results of the analyses of Illinois River water taken above Grafton with the results in Table 55 indicated that a condition of organic purification at its mouth had been reached comparable with or similar to that found in the tributaries; in fact, that this reduction had proceeded to a point at which apparently the limit of oxidation of the organic matter had been reached, and the organic residues that were left were of a stable type, very resistant to all oxidizing influences, a condition characteristic of organic matter of vegetable rather than of animal origin. It was further stated by the witness that the water at the mouth of Illinois River is better than that of Kankakee, Fox, and Little Vermilion rivers, and that the average of all the results from the tributaries showed a condition of organic impurity as great as that of the Illinois at its mouth. (4072–4076.)

Continuing his discussion of the results for 1888 and 1889, the witness stated that Table 54 shows a considerable reduction of organic contamination between Bridgeport and Grafton, although much less in 1889 than in 1888. The difference is particularly noticeable in the oxygen consumed and the albuminoid ammonia and in a less degree in the free ammonia. These three determinations are particularly instructive in the samples taken at Pekin during the winter. Whereas in the summer the amounts of organic matter as disclosed by these determinations do not appear to be excessive, during the winter of 1888 and 1889 the evidence shows a largely increased organic contamination, the explanation for which is not difficult. During the summer, in the stretch of river between Peoria and Pekin, which is nearly level for 8 or 10 miles, an enormous bacterial or fermentative decomposition of organic matter occurs, as is shown by the rapid evolution of gases and the general appearance of the stream, so that roughly this stretch may be compared to a great septic tank in which hundreds of tons of organic matter are constantly undergoing decomposition. This rate of decomposition varies according to the temperature, and therefore in the winter season the rate is much lower, so that at Pekin, below the distilleries and cattle sheds of Peoria, the enormous pollution, as shown by residual albuminoid ammonia and oxygen consumed, indicates fresh and recent additions. The consideration of these figures shows that beyond any question whatever the addition of filth at Peoria is a very important factor in accounting for the organic matter in the river below. Another feature of importance is the high free and albuminoid ammonia and oxygen consumed in the samples taken from Illinois River at Grafton, where the individual analyses show great variations. In the last examinations, made in March, 1899, these factors were unusually high. It is evident that at that time the river must have received a greatly increased amount of

contamination, possibly from the breaking up of ice and the washing down of accumulated filth. (4079–4081.)

The witness then testified with reference to some investigations made in the winter of 1890 and 1891, to determine, if possible, the proportion of organic matter discharged from the sewers of the city to that from the stock yards and the proportion passing the pumps at Bridgeport. Altogether about 130 analyses were made. The water was collected daily through a considerable period at fifteen-minute intervals. The collections were united in large hogsheads, thoroughly mixed, and a composite sample taken each day for analysis. The analyses were made to determine the total organic matter as accurately as possible, and also the nitrogen, from which a check calculation was subsequently made. As a result of these examinations, the witness estimated that the organic matter discharged from the city and the stock-yard sewers in the neighborhood of the Bridgeport pumps amounted approximately to 240 tons daily. The examinations were made as follows: Measured portions of the sample were evaporated to dryness in a platinum dish and the residue incinerated by what is known as the Drown method. In all cases this test was made, from 500 cubic centimeters to 1 liter of sewage being used, according to its concentration. A determination of the total organic nitrogen was made by the Kjeldahl process. Similar examinations were made of the water as it passed the Bridgeport pumps to determine what part of the organic matter was probably decomposed within the city and what part actually passed through the pumps into the canal. It was found in one series of investigations that about five-sixths of the sewage passed through the pumps, the remainder being decomposed inside the city. In the warmer months a very much larger proportion of the organic matter was decomposed in the city than in the colder months. (4095–4098.)

The witness then stated that a comparison of the results obtained in the examinations of 1886 with those of 1888 and 1889 indicated increased pollution of Illinois River at Peoria. (4098–4099.)

In the summer of 1899 the witness was authorized to begin a chemical examination of the waters of Illinios River and its tributaries and the Illinois and Michigan Canal. Before beginning the analyses he made a trip of inspection down the river from Bridgeport to Grafton in company with Jacob A. Harman, engineer of the State board of health. The trip was made for the purpose of familiarizing the two officials with the locations and general conditions along the river and of engaging water takers to obtain samples of water from the various points and ship them to Chicago. The points selected are shown in Table 56. (4104–4108, 4121–4122.)

TABLE 56.—*Sampling points in Illinois River basin, 1899.*

Sampling point.	Collector.	Number of samples.	Remarks.
Illinois and Michigan Canal at Bridgeport.	Frank Wright	21	50 feet west of pumping station.
Illinois and Michigan Canal at Lockport.	P. O'Brien	22	200 feet east of main bridge.
Desplaines River at Libertyville	Clare Sherman	4	
Desplaines River at Lockport	P. O'Brien	27	Above stone bridge north of town.
Desplaines River at Joliet	B. F. Long	17	Basin above city.
Illinois River at Morris	Dr. H. M. Ferguson	22	Wagon bridge south of city.
Illinois River at Ottawa	Dr. W. A. Pike	22	200 yards above mouth of Fox River.
Illinois River at La Salle	C. H. Nicolet	21	600 feet above Vermilion River.
Illinois River at Henry	H. J. Gregory	19	600 feet above dam above town.
Illinois River above Peoria	C. F. Hixon	15	At the Narrows, Averyville.
Illinois River below Peoria	Henry Ocker	21	Opposite Wesley.
Illinois River below Pekin	H. D. Jensen	19	Below outlet of cattle sheds.
Illinois River at Havana	S. F. Kyle	2	200 yards above wagon bridge.
Illinois River above Havana	do	16	Above Spoon River during remainder of sampling period.
Illinois River at Pearl	E. H. Chandler	18	At Alton Railroad bridge.
Illinois River at Grafton	F. M. Calhoun	21	1½ miles above town.
Kankakee River at South Bend, Ind.	Dr. G. W. Van Benschotten.	3	Near the city.
Kankakee River below Wilmington.	C. D. Cassingham	9	
Fox River at McHenry	Dr. C. H. Fegers	3	
Fox River at Ottawa	Dr. W. A. Pike	6	100 yards above Rock Island bridge, temporary station; afterwards from Fox River feeder.
Vermilion River at Pontiac	Dr. J. J. Stites	3	
Vermilion River at La Salle	C. H. Nicolet	8	2 miles above city.
Spoon River at Dahinda	Dr. J. B. Bedford	3	
Spoon River at Havana	S. F. Kyle	4	Several hundred feet above city.
Sangamon River at Mahomet	Dr. J. H. Gardiner	3	
Sangamon River 200 yards above mouth.	G. P. Hollingsworth	7	
Mississippi River at Grafton	F. M. Calhoun	13	Above mouth of Illinois River.
Dupage River at Wheaton	Dr. C. F. Blanchard	3	
Mackinaw River at Kappa	Dr. R. E. McKenzie	2	

In this series of investigations two samples of water were taken at each point, one in a gallon bottle for chemical analysis and the other in a 6-ounce bottle for the bacteriological examination. The methods of sampling and the precautions taken against infection coincided with those usually prescribed. The bacterial sample was placed in a small tin can and this in a larger can, the inner can being surrounded with ice. The samples were sent to Professor Long's laboratory by express, the quickest route being taken in every case. When the samples were received at the laboratory they were marked with serial numbers for identification. The large sample was immediately subjected to analysis, while from the smaller one was taken a portion of the water for that part of the biological examination carried on by Doctor Long and the remainder turned over to Dr. Robert F. Zeit, biologist, who occupied quarters in the same building. (4111–4114, 4119–4120.)

The witness then described the variations in the methods of analysis used in this period of the work from those described for former periods. The Gries method was used to determine nitrites and the phenol-sulphonic method for nitrates. In some cases total organic nitrogen

was determined by the Kjeldahl process. In addition to the generally recognized chemical tests, the witness made certain bacteriological examinations, such as the number of bacteria per cubic centimeter; the coagulation of milk, the amount of gas formed in the fermentation of glucose broth, and the production of indol. In Table 57 are contained averages of weekly analyses of water made according to the above-stated plan from each of the sampling points. The results recited by the witness consisted of the individual analyses, and the reader is referred to the record, pages 4130–4157, or to the special report of the Illinois State board of health for 1901 for a complete statement. The chemical averages given in Table 57 are in nearly all cases representative of the actual results. The bacteriological data, however, vary more widely and the averages given are of less value—so much less in the statements of bacteria per cubic centimeter that the extreme counts are given in all cases.

There was a great diminution in organic pollution of Illinois River between Bridgeport and Averyville, as shown by the decrease in the amounts of oxygen consumed, albuminoid ammonia, and free ammonia, and the increase in nitrates. The amount of oxygen consumed by the river water above Peoria does not differ appreciably from that shown by the tributaries of the Illinois. The same is true of the albuminoid ammonia, while the amount of this ingredient below Peoria is nearly as great as that at Bridgeport. It was further pointed out that after passing Peoria the free ammonia increased from less than 1 part to over 4 parts per million, while the oxygen consumed increased in unfiltered water from 6 to 17 parts per million and in filtered water from 5½ to 13 parts per million, showing that a very great amount of organic matter is added to the river from the industries at Peoria. Down the river from Peoria there is a gradual decrease in the amount of oxygen consumed by the water and in the free and albuminoid ammonia present, indicating that the same processes of purification are effectual in the stretch of the river below Peoria as above. The determinations show, according to the witness, that by the time the water reaches Grafton the organic pollution is not essentially different from that observed in the tributaries of the Illinois. Taken as a whole, the tables disclose two main sources of contamination, namely, the sewage from Chicago and the industrial wastes from Peoria. In the opinion of the witness, the Peoria industrial wastes, rather than the Chicago sewage, constitute the main factor in the contamination of Illinois River at its mouth. (4160–4162.)

TABLE 57.—*Averages of results of weekly analyses of water from Illinois River drainage area at stated points, 1899.*

[Chemical results in parts per million.]

Sampling point.	Number of samples.	Solids.			Ammonia.		Nitrites.	Nitrates.	Oxygen consumed.		Chlorine.	Bacteria per cubic centimeter.	Per cent of gas fermented.			Coagulation of milk.	Indol produced (per cent of samples).
		Total.	Suspended.	Dissolved.	Albuminoid.	Free.			Total.	Dissolved.			0.1 cc.	1.0 cc.	1.0 cc.		
Illinois and Michigan Canal at Bridgeport.	21	536.5	63.5	473.0	3.22	19.84	0.03	0	26.65	15.95	95.47	63,000 to 2,982,000	29.6	41.4	39.4	Rapid.....	71.4
Illinois and Michigan Canal at Lockport.	22	558	67	491	3.37	19.85	.03	.03	27.90	17.31	96.97	38,400 to 1,750,000	24.7	36.4	38.3	.....do.....	59.1
Desplaines River at Libertyville	4	527	15	512	.46	.081	.02	Trace.	5.18	4.88	3.30	1,400 to 9,000	30.0	6.2	.....	Moderate...	0
Desplaines River at Lockport..	7	389	16	373	.559	.229	.009	.045	8.05	6.96	5.98	700 to 108,900	.....	4.3	1.0	Slow.....	0
Desplaines River at Joliet.....	17	591	104	487	2.88	16.05	.015	.014	25.69	15.10	85.49	26,000 to 1,688,400	25.6	28.8	41.2	Rapid.....	41.2
Illinois River at Morris.....	22	445	25	420	1.20	10.99	.18	.07	9.16	8.07	61.8	10,200 to 3,514,500	26.7	28.4	35.5	.....do.....	31.8
Illinois River at Ottawa.....	22	445	11	434	.62	6.23	.61	.74	7.13	6.52	57.4	990 to 371,000	18.6	17.5	23.2	Moderate...	27.3
Illinois River at La Salle.....	21	436	21	415	.58	4.66	.35	1.45	6.99	6.44	41.3	1,200 to 147,000	41.5	38.1	29.4	Rapid.....	42.9
Illinois River at Henry.....	19	451	25	426	.553	3.28	.517	1.39	7.00	6.28	43.2	750 to 3,591,000	31.8	36.6	32.5	.....do.....	36.8
Illinois River above Peoria.....	15	422	24	398	.572	.895	.141	1.10	6.86	5.46	33.04	200 to 864,350	18.2	32.7	31.2	Slow.....	6.6
Illinois River at Wesley.....	21	493	55	438	3.20	4.36	.026	.106	17.44	12.84	34.97	36,300 to 23,688,000	14.2	19.3	33.3	Very rapid..	42.9
Illinois River at Pekin.....	19	419	26	393	.828	1.39	.273	.71	7.81	6.41	34.76	7,200 to 2,378,500	15.8	23.9	23.3	Rapid.....	44.0
Illinois River at Havana.....	18	432	51	381	.695	1.69	.21	1.02	7.18	5.96	29.17	1,800 to 363,000	37.5	37.0	30.0	.....do.....	33.3
Illinois River at Pearl.....	18	388	71	317	.672	.315	.06	.79	5.51	4.73	18.73	100 to 585,000	13.9	23.0	20.5	Slow.....	16.6
Illinois River at Grafton.....	21	362	56	306	.455	.247	.045	.59	5.61	4.65	17.50	350 to 2,709,000	28.0	20.0	5.5	.....do.....	9.5
Mississippi River at Grafton...	13	278	109	169	.443	.080	.001	.03	8.52	6.82	1.77	1,050 to 5,859,600	20.0	25.4	9.4	.....do.....	0
Kankakee River at South Bend, Ind.	3	432	9	423	.29	.063	0	3.00	5.65	5.38	1.17	1,600 to 46,200	40.0	43.3	.....	Moderate...	66.6
Kankakee River at Wilmington	9	322	37	285	.337	.082	.014	.93	5.71	5.09	2.79	780 to 285,120	11.0	11.7	14	.....do.....	11.1
Dupage River (West Fork) at Wheaton.	3	515	31	484	.23	.136	.01	.....	3.70	2.42	3.77	2,200 to 28,800	5.0	5.0	.....	Slow.....	0
Fox River at McHenry.....	3	320	17	303	.421	.147	0	0	5.06	4.93	3.53	2,600 to 32,000	20.0	13.0	.....	.....do.....	0
Fox River at Ottawa.....	6	349	35	314	.454	.145	.007	.11	7.30	5.58	3.78	1,400 to 42,000	5.8	4.0	2.0	.....do.....	0
Vermilion River at Pontiac.....	3	358	13	345	.24	.117	Trace.	.9	3.86	2.98	3.06	4,900 to 36,000	20.0	15.0	.....	Rapid.....	33.3
Vermilion River at La Salle.....	8	914	40	874	.199	.286	.102	.61	3.60	2.95	38.35	600 to 77,000	.....	25.0	22.5	Slow.....	0
Spoon River at Dahinda	3	384	31	353	.282	.098	0	.52	4.24	3.76	9.82	40,100 to 208,400	48.3	36.6	.....	Rapid.....	66.6
Spoon River at Havana.....	4	440	207	233	.496	.302	.04	.27	7.84	4.94	4.17	1,100 to 6,200	27.5	14.0	.....	Slow.....	0
Sangamon River at Mahomet...	3	343	44	299	.36	.13	.002	.....	4.88	3.62	1.85	4,500 to 27,700	33.3	20.0	.....	.....do.....	33.3
Sangamon River near mouth...	7	346	29	317	.320	.146	.03	.22	4.09	3.42	7.71	650 to 6,600	.....	21.0	.....	.....do.....	0
Mackinaw River at Kappa.....	2	356	45	311	.493	.165	.015	.70	6.04	4.96	2.83	14,000 to 30,300	32.5	25.0	.....	.....do.....	50.0

The witness then compared the results of analyses of samples taken from Desplaines River at Joliet with those from Illinois River at Wesley, below Peoria, and pointed out that the amount of albuminoid ammonia is greater at Wesley. As indicated by the oxygen consumed, the amount of organic matter in the water at Wesley is nearly as great as that at Joliet. This apparent discrepancy was explained by the witness to be due to the fact that the albuminoid-ammonia determination is a measure of the nitrogenous matter, whereas the oxygen-consumed determination measures the carbonaceous matter. As the waste from Peoria is known to be largely nitrogenous, the albuminoid ammonia would be relatively greater at Peoria, while the carbonaceous matter would be predominant at Joliet. Concerning the water above Peoria the witness asserted that it was not essentially different from the waters of the ordinary streams of the State of Illinois and no more contaminated than might be expected of a water which had passed through soil rich in organic matter. He then compared the water from the Illinois above Peoria with that of Fox River and stated that the Fox at Ottawa contains as much organic matter as the Illinois at Peoria. Free ammonia in Fox River is very much less than that at Peoria, but the albuminoid ammonia is almost as great. Comparing conditions at La Salle and Pekin, the witness stated that the amount of organic matter at Pekin, as indicated by the albuminoid ammonia, is much greater than at La Salle, while the free ammonia at La Salle is greater than that at Pekin, indicating that the oxidation of organic matter at La Salle is the more nearly complete. If, however, the contamination be measured by the oxygen consumed, the condition at the two places is similar. Comparing the waters of Illinois River above Peoria with those above Grafton, the witness stated that, as measured by the figures for oxygen consumed and for free and albuminoid ammonia, there is somewhat more organic pollution indicated above Peoria than at Grafton. He then made a comparison between the water above Peoria and that of the Mississippi above Grafton, stating that the oxygen-consumed determinations show that Mississippi River water at Grafton contains more organic matter than the Illinois, while the two compare very closely when measured by the albuminoid-ammonia tests. Other determinations show that in the Illinois at Grafton there is evidence of a large amount of nitrogenous matter which has undergone oxidation. From all the above considerations the witness concluded that the organic matter discharged at Bridgeport into the Chicago drainage canal has undergone practically complete oxidation before it has reached the mouth of Illinois River, because at this point he could find no more organic matter than might readily be accounted for by that discharged from the tributaries and from contamination at Peoria. (4163–4166.)

The witness stated that the bacteriological results agree with the chemical results. (4167–4170.)

He then read into the record the results of his examinations during 1900. The averages are reproduced in Table 58. (4172–4205.)

The witness stated that Table 58 discloses considerably less organic contamination in both canals at Bridgeport than appeared during the series of 1899. At Morris, where there is a considerable mixing of waters from both canals, the amounts of free and albuminoid ammonia are lower than those for 1899. When Wesley is reached there is a great increase in the figures for all constituents, being more marked in oxygen consumed and free and albuminoid ammonia. At Pearl the condition of the water is as good as that shown in many of the tributaries, but at Grafton the amount of organic matter is slightly greater than at Pearl. In the opinion of the witness the point of greatest importance in the spring series of analyses was the very marked increase of organic matter at Peoria and Wesley, as compared with the amount found at points above during the same examination. The witness compared the conditions at Wesley and at Morris for the purpose of showing that the organic matter is greater at the former place; another comparison showed that the water at Morris is purer than at Grafton. Comparing the conditions at Morris in 1899 and the spring of 1900 the witness stated that the amount of organic matter was less at the later date. This was true at Wesley also and in general throughout the course of the river, except at Grafton, where more organic matter seemed to be present in 1900 than in 1899. The river was high during the spring of 1900, and therefore the comparison between the waters of the river at that time and during the summer conditions which prevailed in 1899 was not fair. (4181–4185.)

Continuing with a discussion of the results of examinations made during the summer of 1900, the witness stated that it was shown at the outset that there was a lower initial contamination of the water at Bridgeport than in 1899, and that the data further showed a gradual and continuous diminution in the factors, indicating organic contamination as the river was descended—a diminution far greater than could be accounted for by the amount of dilution entering the main stream from its tributaries. The water from Illinois River above Peoria, according to the results for oxygen consumed and for free and albuminoid ammonia, had no greater degree of contamination than is ordinarily found in the tributary waters of the Illinois. At Wesley there was a remarkable increase in the organic pollution, amounting to several hundred per cent, as shown by the free and albuminoid ammonia determinations. It is known that the contamination entering the river at Wesley is largely nitrogenous, and therefore there was at this point a much greater increase in the albuminoid and free ammonia than in the oxygen consumed.

FEBRUARY TO APRIL.

Sampling point.	Number of samples.	Solids. Total.	Solids. Suspended.	Solids. Dissolved.	Ammonia. Albuminoid.	Ammonia. Free.	Nitrites.	Nitrates.	Oxygen consumed. Total.	Oxygen consumed. Dissolved.	Chlorine.	Bacteria per cubic centimeter.	Per cent of gas fermented. 0.1 cubic centimeter.	Per cent of gas fermented. 1.0 cubic centimeter.	Organic nitrogen.	Coagulation of milk.	Indol produced (per cent of samples).	Loss on ignition. Total.	Loss on ignition. Dissolved.
Illinois and Michigan Canal at Bridgeport.	1	694	224	440	2.50	6.00	0.03	0.00	24.96	11.68	95.9	540,000	20	30	9.10	Rapid.....	100	140	72
Drainage canal at Western ave..	7	221	23	198	1.04	1.78	.05	.11	7.82	4.77	11.7	26,500 to 810,000	17	33	2.78	.....do.....	100	47	43
Illinois River at Morris.....	8	305	74	231	.69	3.13	.06	.57	9.26	6.07	12.3	54,000 to 3,820,000	30	57.5	.....	Very rapid..	100	54	45
Illinois River at Wesley.....	8	342	98	244	2.21	3.06	.05	.37	16.93	11.48	9.1	9,600 to 2,752,000	24.4	32.5	.....	.....do.....	87.5	82	61
Illinois River at Havana.....	9	268	50	218	.55	.86	.05	1.11	8.34	6.39	5.2	4,300 to 1,309,000	14	13.3	.....	Rapid.....	44.4	47	40
Illinois River at Pearl.....	8	458	262	196	.45	.46	.07	1.18	9.28	5.05	4.3	4,600 to 158,400	15.6	32	.....	.....do.....	28.6	53	39
Illinois River at Grafton.....	11	600	407	193	.66	.50	.04	1.02	10.47	5.40	4.8	4,700 to 106,800	14.4	34	1.58	Moderate...	22.2	61	42
Spoon River at Havana.....	7	699	489	210	.87	.76	.07	.83	16.66	5.13	4.5	6,200 to 386,400	13	26	.....	.....do.....	28.6	71	31

MAY TO OCTOBER.

Sampling point.	Number of samples.	Solids. Total.	Solids. Suspended.	Solids. Dissolved.	Ammonia. Albuminoid.	Ammonia. Free.	Nitrites.	Nitrates.	Oxygen consumed. Total.	Oxygen consumed. Dissolved.	Chlorine.	Bacteria per cubic centimeter.	Per cent of gas fermented. 0.1 cubic centimeter.	Per cent of gas fermented. 1.0 cubic centimeter.	Organic nitrogen.	Coagulation of milk.	Indol produced (per cent of samples).	Loss on ignition. Total.	Loss on ignition. Dissolved.
Illinois and Michigan Canal at Bridgeport.	15	447	64	383	2.55	15.26	0.17	0.13	16.31	9.11	89.7	306,000 to 2,460,000	17	19	13.85	Very rapid..	14.3	76	54
Drainage canal at Western ave..	14	203	25	178	.95	1.34	.11	.12	6.28	4.42	9.2	170,000 to 1,656,000	15	19	2.58	.....do.....	*35.7	44	38
Drainage canal at Lockport....	11	212	19	193	.76	2.16	.06	0.00	5.29	4.34	12.6	82,000 to 1,860,000	30.5	45	.....	.....do.....	40	42	34
Desplaines River at Joliet.....	15	280	35	245	.85	4.66	.09	.02	6.97	4.52	31.4	4,500 to 896,000	29	27	.....	.....do.....	40	54	44
Illinois River at Morris.....	15	251	29	222	.63	2.84	.27	.17	6.40	4.66	17.8	2,000 to 550,000	26	35	.....	Rapid	26.7	44	39
Illinois River at Ottawa.....	15	266	28	238	.39	.81	.37	.92	5.94	5.03	17.2	2,500 to 127,200	37.7	36	.....	Moderate...	15.4	50	44
Illinois River at La Salle.....	15	278	26	252	.36	.55	.25	.77	5.60	4.83	15.8	1,800 to 150,000	38	36	.....	Rapid.....	35.7	48	44
Illinois River at Henry.....	15	283	35	248	.40	.41	.22	1.06	5.86	4.86	16.9	500 to 202,500	21	36	.....	Slow.....	13.3	51	44
Illinois River above Peoria.....	13	265	21	244	.34	.21	.12	.05	5.05	4.53	15.5	2,000 to 472,500	18.6	30	.....	.....do.....	9.0	49	43
Illinois River at Wesley.....	16	333	71	262	1.34	1.62	.11	.72	9.91	4.59	16.6	23,500 to 24,000,000	13.3	13	.....	Rapid.....	13.3	65	52
Illinois River below Pekin.....	15	326	76	250	.46	.39	.17	.74	7.01	5.31	15.0	6,500 to 450,000	23.5	23	1.34	.....do.....	35.7	53	46
Illinois River at Havana.....	15	322	77	245	.41	.41	.18	.77	6.46	4.14	15.0	2,500 to 345,600	37	40	.....	Moderate...	14.3	55	48
Illinois River at Pearl.....	14	450	198	252	.43	.12	.07	.75	6.87	5.06	11.6	500 to 330,000	24.6	17	.....	.....do.....	0.0	55	59
Illinois River at Grafton.....	17	331	88	243	.36	.07	.03	.87	5.85	4.82	10.6	1,200 to 161,000	26.5	28	.....	.....do.....	0.0	57	47
Mississippi River at Grafton...	6	347	195	152	.54	.07	.02	.03	11.73	7.8	2.0	2,000 to 62,000	20	26	1.49	.....do.....	0.0	53	40
Fox River at Ottawa.....	3	312	20	292	.50	.11	.02	0.00	6.77	6.32	4.9	6,500 to 2,232,000	25	27	1.25	Slow.....	0.0	79	72
Vermilion River at La Salle....	3	283	45	238	.32	.12	.10	.43	5.89	5.23	9.5	4,500 to 25,500	23.3	33	1.30	.....do.....	33.3	63	48
Spoon River at Havana.....	4	328	104	224	.47	.27	.08	.08	7.96	5.56	4.4	14,800 to 193,000	34	35	1.41	.....do.....	25	53	40
Sangamon River near mouth...	3	367	90	277	.35	.06	.20	.35	6.32	5.57	7.1	2,500 to 13,000	43	23	1.23	.....do.....	0.0	61	49
Kankakee River at Wilmington.	3	299	55	244	.46	.10	.06	.77	9.20	7.68	1.8	1,200 to 45,500	37	33	1.40	.....do.....	33.3	57	53

Below Wesley the pollution decreased steadily and at Pekin the albuminoid ammonia had been reduced to a point which was comparable with that found in ordinary river waters of the State, and beyond which the reduction does not commonly proceed for the reason that the organic substances remaining are of the comparatively stable types, which are not subject to great reduction by bacterial oxidizing agents. In the case of the free ammonia, however, the witness stated that as this substance does undergo change there was a progressive improvement or disappearance by oxidation to the mouth of the river. The figures for the oxygen consumption indicated a similar condition, the amount lessening from Pekin to Grafton, where it corresponded to that shown by the waters of the tributaries entering the Illinois. (4209–4210.)

The witness then drew several comparisons from his table, beginning with a calculation of the combined flow through the Chicago drainage canal and the Illinois and Michigan Canal. According to the observations of the engineering department of the sanitary district of Chicago, as reported by the chief engineer, 16 per cent of the flow of water from Lake Michigan into Desplaines River went through the Illinois and Michigan Canal and 84 per cent through the drainage canal. If it were assumed that all of the water passed through one channel, the volume being equivalent to the volume flowing through both, the constituents in that channel would be as follows, in parts per million: Albuminoid ammonia, 1.13; free ammonia, 3.9; oxygen consumed, 7.46; chlorine 23.5. These numbers may be taken as representing the composition of the total flow through the two channels. A comparison of these numbers with the data for the water at Joliet showed a discrepancy, which was accounted for by the witness as being due to an imperfect mixture of the Desplaines and canal waters. Because of this discrepancy the Joliet collection was not considered in preparing the series of charts that were then presented by the witness, based on the results of analyses made during the summer of 1900, showing amounts of albuminoid and free ammonia, oxygen consumed, and chlorine at the various sampling points from Bridgeport to Grafton. As the values expressed in these charts are included in Table 58, they are not reproduced. (4210–4223.)

Professor Long then testified that he had made further chemical surveys in 1901, from September to December, inclusive, and in 1902 during February and March, the sampling points being Illinois River above its confluence with the Mississippi, Mississippi River above the mouth of the Illinois, and Missouri River above its confluence with the Mississippi. The results of these examinations were read into the record and occupy pages 4230 to 4237, inclusive. The averages of these results are given in Table 59, and the reader is referred to the record or to the report of the Illinois State board of health for 1902 for more detailed information.

TABLE 59.—*Averages of results of analyses of water from Illinois, Mississippi, and Missouri rivers, 1901 and 1902.*

	Illinois River above Grafton, September 23 to December 12, 1901.	Mississippi River above Grafton, September 23 to December 12, 1901.	Missouri River at mouth, September 17 to December 12, 1901.	Illinois River above Grafton, February 21 to March 18, 1902.	Mississippi River above Grafton, February 24 to March 17, 1902.	Missouri River at mouth, March 10 to 21, 1902.
Number of samples	38	37	43	13	12	8
Total solids.....parts per million	261	183	1,294	445.7	280.8	1,594.5
Solids in suspension.....do	32	38	948	216.0	93.0	1,290.2
Solids in solution.....do	229	45	346	229.7	187.8	304.3
Loss on ignition:						
Total.....do	40	36	82	68.4	48.9	186.0
In solution.....do	36	33	29	45.8	49.3	54.0
Albuminoid ammonia.....do	0.413	0.39	0.60	0.452	0.283	0.849
Free ammonia.....do	0.238	0.07	0.10	1.344	0.244	0.295
Nitrites.....do	0.234	0.004	0.0006	0.003	0.003	0.011
Nitrates.....do	1.042	0.08	0.13	0.398	0.473	0.675
Oxygen absorbed:						
Total.....do	4.31	7.84	10.28	8.96	7.09	17.15
In solution.....do	3.21	6.53	3.17	4.88	4.84	4.96
Organic nitrogen.....do	0.81	0.74	1.61	1.46	1.24	3.27
Chlorine.....do	16.4	1.88	14.9	12.49	2.45	14.46
Bacteria per cubic centimeter	100 to 25,800	150 to 5,200	300 to 21,200	40 to 14,880	60 to 12,400	160 to 14,160
Fermentation:						
In 0.1 c. c.....per cent of gas	31.4	36.1	82.5	61.6	25.0	87.5
In 1 c. c.....do	48.6	51.4	88.4	40.0	9.0	.....
Coagulation of milk at 38° C	Slow.	Slow.	Moderate	Moderate	Slow.	16.75 hrs.
Production of indol..per cent of samples	2.9	3.1	56.8	15	25.0	75

The witness made the following interpretation of the data contained in Table 59: The organic condition of Illinois River above Grafton is much better than that of the Missouri above its mouth. This is shown, according to the witness, first, by the factor of oxygen consumed, which for Illinois River is for the unfiltered water 4.31 parts per million and for the filtered water 3.21 parts, whereas the Missouri shows 10.28 and 3.17 parts, respectively; second, by the factor of albuminoid ammonia, as measuring the substances of comparatively complex composition yet undecomposed—in Illinois River 0.413 part per million, as against 0.6 part in Missouri River; third, by the factor of organic nitrogen, as determined by the Kjedahl process, which is 0.81 part per million in Illinois River and 1.61 parts in the Missouri. The chemical reactions due to living organic matter in Illinois and Missouri rivers being considered, it is evident, according to the witness, that the condition of Illinois River was greatly superior to that of Missouri River throughout the whole period, and especially is this shown by the biological work recorded in the table. The production of indol, for example, was very common in samples taken from Missouri River and rare in Illinois River samples. It is also shown by the greater abundance in the Missouri samples of those organisms which have the power of breaking down carbohydrates with the production of acid. The tests further show, according to the witness, that Missouri River is also contaminated to a far greater degree than Mississippi River above the mouth of the Illinois. (4239–4241.)

The witness was then questioned concerning investigations mad by him on the character of the water of Kaw and Missouri rivers i the vicinity of Kansas City. He stated that in May, 1903, sample were taken under his direction from Kaw River at a point 1½ mile above its confluence with the Missouri and from Missouri River (a above its confluence with the Kaw, (b) below the confluence with th Kaw and above Kansas City, and (c) below Kansas City. No deter minations were made on these samples except that of chlorine. Th results, together with the flow of Kaw and Missouri rivers, a recorded in Table 60. (4241–4246.)

TABLE 60.—*Volume of flow and determinations of chlorine in the water of Kaw an Missouri rivers at designated points, May 22–28, 1903.*

[Flow in cubic feet per second; chlorine in parts per million.]

	May 22.		May 23.		May 24.	
	Flow.	Chlorine.	Flow.	Chlorine.	Flow.	Chlorin
Kaw River	.....	.....	.....	.....	51,000	.....
Missouri River above Kaw River	.....	10.22	.....	11.64	.....	.....
Missouri River above Kansas City	125,000	10.95	145,000	11.62	184,000	.....
Missouri River below Kansas City	.....	16.59	.....	11.72	.....	.....

	May 25.		May 26.		May 27.		May 28.	
	Flow.	Chlorine.	Flow.	Chlorine.	Flow.	Chlorine.	Flow.	Chlorine
Kaw River	49,600	.....	39,100	10.29	63,500	9.89	72,200	8.
Missouri River above Kaw River	.....	9.81	.....	.....	.....	.....	.....	.....
Missouri River above Kansas City	198,000	10.31	226,000	.....	242,000	.....	310,000	.....
Missouri River below Kansas City	.....	11.96	.....	.....	.....	.....	.....	.....

It appears from Table 60 that the samples from Kaw River we taken subsequent to those from the Missouri, and therefore th amounts of chlorine as stated in the table are not absolutely con parable for the two streams. The dates May 26, 27, and 28, give in the record, are probably incorrect, owing to typographical erro and the proper dates are the 22d, 23d, and 25th, as in the case of th Missouri River samples. As this review is taken from the offici record, however, this probable error can not be corrected, but it here indicated.

Counsel for the defense stated that the testimony here given w partly for the purpose of rebutting that of Doctor Teichmann, wh stated that the great part of the chlorine in Missouri River w derived from the Kaw. In response to questions, therefore, th witness interpreted the results as follows: The averages drawn fro the table show a considerably larger figure for chlorine below Kans City than in the Kaw or the Missouri above Kansas City. The exce of chlorine below Kansas City is more than can be accounted for b any addition from the Kaw, showing that a certain proportion mu come from the stock yards and sewers of Kansas City. The volu

of Missouri River was considerably greater than that of the Kaw throughout the period under discussion and the amount of chlorine in the Kaw, the volume of the river being considered, could not have increased the chlorine in the Missouri beyond the amount given for the latter river above Kansas City. Therefore, in the opinion of the witness, the chlorine at the mouth of Missouri River can be attributed only in part to the chlorine from Kaw River, the table showing that the additions from Kansas City are an important factor. (4241–4249.)

With reference to the effect of sewage from the Chicago drainage canal on the water supply of St. Louis, the witness stated that from all the examinations he had made of Illinois River and its tributaries, it was his opinion that no part of the original organic matter leaving Chicago through the drainage canal and finding its way into Illinois River could reach the mouth of the Illinois, much less the intake tower of the St. Louis waterworks; therefore it was his belief that the sanitary condition of the water supply of St. Louis was not and could not be injured by any pollution from Chicago. (4250.)

The witness then stated that the volume of water going down Illinois River is greater than it was before the opening of the drainage canal, and that inasmuch as the amount of sewage per given volume is necessarily less and at the same time this dilution produces no enforced decrease in the bacterial activity throughout the channel, there can be no decrease in the purification from these causes. Floods carry into the river an immense amount of organic matter and numerous living organisms from all the tributaries. This increases the organic contamination, irrespective of any original contamination which may have been present. A further effect of floods, inasmuch as the banks of Illinois River are very low, is to spread an enormous volume of water over an area of many hundreds of thousands of acres, providing for the sedimentation and oxidation to a marked degree of matters carried by the water at these periods. The conditions in Illinois River, because of the peculiar character of the banks, are unique in this respect. The overflow disposes in this manner of a vast amount of organic matter which in a stream with high banks would have to be carried forward. Inasmuch as by far the largest part of the water at flood times leaves the natural channel of the river and is distributed over a vast area of land, the original sewage or remnants of sewage carried by this water must be in like manner distributed, and thus made accessible to the purifying processes of sedimentation or oxidation. The witness then stated that the lakes which were backed up by the various dams across Illinois River offer large basins for oxidation and hold up the water to some extent for that purpose. He further stated that it was his belief that Mississippi River at Chain of Rocks is not a potable stream and

had not been at any near period suitable for household use. (4250–4253.)

In response to questions, Professor Long stated that the addition of a large volume of Lake Michigan water and canal water flowing down the Illinois, which causes an increase in dilution, had produced the resultant effect that the water at the mouth of Illinois River after the opening of the canal was in far better sanitary condition than previous thereto. (4254.)

The following hypothetical question and the reply thereto appear in the record (pp. 4256–4260):

Q. Professor, assume that 107 barrels of 40 gallons each of culture of *Bacillus prodigiosus*, consisting of 1,000,000,000 bacilli per cubic centimeter as contained in said barrel, were deposited into the Chicago drainage canal at the town of Lemont on the afternoon and evening of the 6th day of November, 1901, during a period of from four to eight hours; assume further that immediately after said barrels were emptied into the drainage canal at the point aforesaid the laboratories established at Lockport, Joliet, Peoria, and Grafton, on the Illinois River, at the intake tower of the St. Louis waterworks at the Chain of Rocks, were notified, and that samples were collected at each of these places every hour of the day and night for the purpose of bacteriological analyses for the ascertainment of these *Bacillus prodigiosus;* and assume that at Lockport these hourly samples taken day and night were taken from November 7 to November 25, a period of eighteen days, the total number of samples taken being 432, or thereabouts; assume that at Joliet these hourly samples taken day and night were taken from November the 7th to November the 25th, a period of eighteen days, the total number of samples taken being about 432; and assume that at Peoria these hourly samples taken day and night from November the 8th to November 30, a period of twenty-two days, amounting to a total of 528, and assume that at Grafton these hourly samples were taken day and night from November 12 to December 15, a period of thirty-three days, the total number amounting to 732, of which 384 were analyzed by Dr. Ravold; and assume that the total number of samples taken hourly day and night was 720, and assume that at the laboratory tap these hourly samples taken day and night from November 20 until March 1, 1902, a period of one hundred days amounting to a total of 2,400, and assume that the total number of samples analyzed at the different points for the period above mentioned was 5,304; and assume further that on December 4 at 8.45 a. m. one bacterium *Bacillus prodigiosus* was found at the intake tower at the Chain of Rocks; assume that on December the 5th at 9 a. m. one bacterium *Bacillus prodigiosus* was found at the intake tower at the Chain of Rocks; assume that on December the 8th at midnight one bacterium *Bacillus prodigiosus* was found at the intake tower at the Chain of Rocks; assume that on December 6 at 8 a. m. at Grafton one *Bacillus prodigiosus* was found; assume that on December 7 at midnight at Grafton one *Bacillus prodigiosus* was found; and assume further that these five organisms were all of the organisms of *prodigiosus* that were found in the examinations made from Lockport to the intake tower at the Chain of Rocks and the laboratory tap in the city of St. Louis, which were made during the progress of this investigation hereinbefore set forth; that at no time was there more than one bacterium found at each of these places. Assuming all of the facts as hereinbefore stated to be true, what is your opinion as to the value of this experiment as indicating the probable longevity of the typhoid bacillus as measured by the longevity of the *Bacillus prodigiosus* and the probability that a typhoid bacillus entering the drainage canal from the sewers of Chicago would ultimately find its way through the Desplaines and Illinois rivers to the town of Grafton?

A. Considering the longevity of the typhoid bacillus as measured by the longevity of the *Bacillus prodigiosus*, which consideration in no way involves a knowledge of bacteriology, but simply a knowledge of arithmetic as set forth in this question, I would say that the suppositions advanced in this question indicate that the longevity of the *Bacillus prodigiosus*, and of the typhoid bacillus as compared with it, is so extremely slight as to make the probability of a germ of this character being able to survive a passage from the drainage canal to Grafton so remote as to be entirely unworthy of consideration. This conclusion depends on certain calculations which I have made and which I will present. As the various data are given in terms of the metric system, it is necessary to make certain reductions in order to be able to reach a proper conclusion. First, it is necessary to determine the concentration of the germs in the canal water at the time when they were dumped from the barrels as supposed in the question. At this period the flow in the canal was almost exactly 235,000 cubic feet per minute, which I have reduced to liters by use of the factor 28.3 liters per cubic foot, which is almost the exact factor, giving 6,650,000 liters, very nearly, per minute. Reducing this number of minutes to hours, I find that for four hours, or two hundred and forty minutes, assumed to be consumed in this addition of the bacteria to the water a volume of water flowed equivalent to 1,596,000,000 liters, or approximately 1,600,000,000 liters. As the calculations are finally based on the cubic centimeter rather than the liter, I have reduced this volume to cubic centimeters by multiplying by 1,000, giving as the volume of this water in cubic centimeters, into which the substance from the barrels was dumped, 1,600,000,000,000, or, expressed most accurately in the method now common among mathematicians, 1.6×10^{12}. This is the flow of the canal in cubic centimeters in four hours. I will say for the purposes of comparison it makes no difference whether we assume four hours or eight hours, as the same factor enters later into the calculation at the mouth of the river. We have next to consider from the assumptions of the question the number of bacteria mixed with this volume. One hundred and seven barrels of 40 gallons each gives the amount of 4,280 gallons, which when reduced to liters give us something over 16,000 liters—16,017 and more liters—but in round numbers I will use 16,000 liters, or 16,000,000 cubic centimeters. The number of bacteria per cubic centimeter, according to the assumption of the question, was 1,000,000,000. The total number of bacteria then discharged would be the product of 1,000,000,000 per cubic centimeter by the number of cubic centimeters, or 16,000,000 multiplied by 1,000,000,000, which multiplied out gives us the number 16,000,000,000,000,000, or, more accurately or definitely expressed, 1.6^{16}. We have therefore as the number of bacteria, following the assumption of the question, which must have been thrown into the canal, 1.6^{16}, as given. As the number of cubic centimeters into which this number was thrown was given as 1.6^{12}, the quotient of one of these by the other gives the concentration of 10 at the fourth power, or 10,000 bacteria to the cubic centimeter, on the assumption that the mixing or dumping took place through a period of four hours. We have therefore as concentration 10,000 to the cubic centimeter. Now, supposing this wedge of water to pass down the river absolutely unchanged, and supposing further that no increase or decrease in this number of bacteria should follow by death or by any other means, it is simply a statement of fact to say that we should find 10,000 per cubic centimeter at some corresponding time, in some part of the river below; but admitting the fact that a change by dilution follows by taking up the water of the tributaries and through the uneven flow of the water, the particles moving more rapidly in the center than along the sides of the stream, a certain dilution must be calculated—must be admitted as taking place in this volume. From the fact that these samples were all found within a four-day period, or rather these bacteria were all found in samples collected in a period of four days, as presented in the question, I have calculated this original volume of water as diluted with the volume of water which flows at the mouth of the river in a period of

four days. On that assumption a number of at least 200 should be found per cubic centimeter for each cubic centimeter examined, on the assumption that no death or loss of these bacteria takes place anywhere in the course. As a matter of fact, not 200 were found in 1 cubic centimeter, but a very large number of examinations had to be made to find a cubic centimeter in which there was one contained. It is evident that an enormous destruction of these organisms must take place between the point at which the bacteria were thrown in and the mouth of the river, where the examinations were made. The actual finding is not over one ten-thousandth of what should be expected from 107 barrels on the assumption that these organisms did not die out; that is, we find less than one ten-thousandth of the expected amount. If we consider a number less than 107 barrels as added—one barrel, for example—the probability of any organism of this character reaching the mouth of the Illinois River is less than one chance in 1,000,000. If we consider one barrel or one one-hundredth of a barrel as added, the chance of one of these organisms reaching the mouth of the river and being found in a cubic centimeter becomes correspondingly reduced. Therefore, without involving any question of bacteriology, but simply a question of calculation, it is evident that the probabilities of any number of bacteria in a given small volume reaching the mouth of the Illinois River is extremely remote and not one which can be practically or seriously considered. (4256–4260.)

Continuing, the witness stated that the longevity of the typhoid bacillus being measured by that of the *Bacillus prodigiosus*, and the fact being taken into account that in the large number of examinations made at Lockport, Joliet, and Peoria no *B. prodigiosus* were found, and further that only the small number mentioned were obtained at the mouth of the river and from the intake tower at Chain of Rocks and in the water supply of St. Louis—none at all before December 4 and none after December 8—it is practically improbable that a typhoid bacillus with longevity and virility as measured by that of the *B. prodigiosus* would ever survive the passage down the drainage canal and Illinois River and enter the water supply of St. Louis. (4261.)

CROSS-EXAMINATION.

In reply to an inquiry concerning which tests, chemical or bacteriological, the witness considered most important, he stated that it was impossible to determine; both are of equal importance in some cases, while in others one will take precedence over the other. He stated further that his direct testimony on the sanitary condition of the water of Illinois River was not altogether based on chemical and bacteriological tests, but also on his general opinion of the sanitary condition of river water. (4264–4266.)

The witness made the following general statement of his opinion concerning pollution and the interpretations of analytical results: The most objectionable pollution in a river consists of the products of human excretion; as to which particular product the witness could not give an opinion as biologist or bacteriologist, but he concurred in general with the accepted opinion. With reference to the specific character of pollution the witness stated that the origin of the vege-

table extracts can be pretty safely inferred, because they contain preeminently more bodies of the carbohydrates and their derivatives than the extracts of animal origin. Vegetable extracts give marked reactions with the permanganate solution, but not very marked reactions with the reagents measuring nitrogenous matter. This peculiarity is of value in distinguishing between the vegetable and animal extracts when the organic matter is fresh, but it does not appear to the same extent in the examination of older substances. It is not always possible to differentiate sharply between water polluted by sewage and that containing organic matter from swamps. In general, waters having the latter contamination contain very much less chlorine than those contaminated by sewage. The amount of nitrogen in different forms is also significant. The nitrogen as nitrites seems to be more characteristic of the breaking down of the products of animal than of vegetable origin. These are the most important factors and the ones usually considered; in addition it is always desirable to have as much knowledge as possible concerning the character of the watershed, the contribution of sewers in general, whether there are great industries and of what kinds, the drainage areas, and the rate and character of flow of the river. Inorganic pollution consists of the mineral salts, which are the combination of the so-called metallic elements, sodium, potassium, calcium, magnesium, and ammonium, with the elements described as chlorine, sulphuric acid, nitric acid, phosphoric acid, and carbonic acid. The substances known as organic are usually complex forms—carbon, nitrogen, hydrogen, and oxygen, with small amounts of sulphur and phosphorus. Organic substances are distinguished from the so-called inorganic matter by the fact that they undergo general decomposition by heat relatively more easily—in other words, the distinction is based on their degree of stability. The witness then related the conventional theory concerning the breaking down of organic matter and described in a general way the leading features of the Chicago sewerage system and its effects on Lake Michigan, Chicago River, and Desplaines River.

Throughout his cross-examination the witness was careful to state that he had confined his work and his interpretations to purely chemical and bacterio-chemical lines and had not attempted to determine the presence of infected matter in the water. He further stated that chemical analysis was beneficial to the sanitarian only to the extent of showing the amount of organic pollution regardless of its character, although under certain conditions it does give a clew to the kind of pollution.

Continuing along the general subject of infection and the relation between polluted waters and water-borne diseases, the witness expressed certain doubts concerning the conclusions of epidemiologists and stated that, while in some cases he was inclined to accept

the opinion of sanitarians without advancing any original theories of his own, he had based his opinion concerning the condition of Illinois River almost solely on the results of examinations of a chemical and bacterio-chemical nature. The matter of possible infection was left out of consideration entirely. He did not consider it an important factor in his investigation, inasmuch as his purpose was not to determine whether or not the water was safe for drinking or domestic purposes, but to determine the extent and rate of destruction of organic pollution in the waters in question and to compare these several waters with each other. He further stated that it was not possible to assign any hard and fast limit to the amount of polluting substances in a water which would be necessary to make it unpotable and refused to be led into a discussion which would make it necessary for him to advance an opinion upon such a subject. In forming his conclusions concerning the water, he had not attached much importance to the opinion of epidemiologists, but had preferred to refer to the work of others who had made investigations parallel to his own. (4266–4298.)

The following hypothetical question was then asked:

Assuming that it required twenty days for the water in Illinois River to run from its source to its mouth prior to the opening of the canal, and that it requires ten days since the opening of the canal, I would like to ask you what effect this time limit has upon the determination of whether or not decomposition has more rapidly taken place during the previous period than the subsequent period.

To this and other questions the witness answered:

This time limit can have no possible bearing on the question of the determination of the fact whether the decomposition has taken place more rapidly or not. The chemical analysis is made irrespective of the rapidity with which the water comes down there. * * * But supposing this more rapid flow is due to enormously greater dilution instead of being more dangerous for household consumption, inasmuch as we are concerned only with a small volume * * * and not with the gross condition, the final condition, instead of being worse, may be better as far as household use is concerned.

Continuing, the witness stated that dilution does not necessarily destroy but it renders less probable the deleterious effect in proportion to the extent of dilution. A comparison of the gross pollution of the Missouri with that of the Mississippi or of the gross pollution of the Illinois with that of the Mississippi is absolutely valueless and absurd. It makes no difference what the volume of the body of water is, the chemist is concerned only with that amount with which one is liable to come directly into contact in his daily usage and as drinking water and the expression parts per million or grains per gallon is the only thing which a practical man has to take into consideration. In expressing results in parts per million, etc., the dilution factor goes in. The witness further insisted that it was impossible to determine in all cases the potability of a water from the analytical results, an

that no fixed standards could be set with reference to the amount of this or that ingredient; in connection with this it was necessary to know all the conditions and the source of the water. The witness then stated that inasmuch as no one had been able to find the typhoid germs in the water, it was his belief that it is highly probable that there is no reason for assuming that they are there under any conditions. (4345–4369.)

ADOLPH GEHRMANN.

DIRECT EXAMINATION.

Adolph Gehrmann was called as a witness in behalf of the defense. In qualifying as an expert he stated that his residence was in Chicago; his profession, physician and bacteriologist. He had been connected with the Chicago department of health—during 1893 as bacteriologist and microscopist for the milk department; and from January, 1894, until June, 1902, as director of the laboratory and bacteriologist for the department. He received his medical degree from Northwestern University in 1890, and had been engaged as a teacher of bacteriology and hygiene in the medical department of the University of Illinois. At the time of his testimony he was professor of hygiene in the Dearborn Medical College and professor of bacteriology in the Harvey Medical College. In connection with his duties as director of the laboratory of the department of health in Chicago, he had conducted the bacterial examinations of samples of water received at the laboratory. During 1893 he made a weekly examination of the water from Lake Michigan from the four cribs, and of one sample from the laboratory tap. From the beginning of 1894 to the end of his service for the department of health samples were taken daily for bacteriological examination. (4744–4747.)

In the early months of 1899 he was instructed by the commissioner of health of Chicago to arrange for the examination of samples from the Illinois and Michigan Canal, Desplaines River, Illinois River and its tributaries, Mississippi River, and Missouri River, and in conjunction with Professors Palmer and Burrill of the University of Illinois and Professor Jordan of the University of Chicago elaborated plans for such examinations. The system of collection was determined and the work was taken up in the laboratories of these two universities and of the health department. It was arranged that from each of the sampling points three separate samples must be collected, each sample to be represented by a large and small bottle, making six bottles in all, and to be identified according to the usual procedure. The collectors were instructed in the customary manner. (4749–4758.)

The following were the sampling points:

Points at which water samples were taken for investigations of Chicago dep health, 1894 to 1902.

Illinois and Michigan Canal:
- Bridgeport, 500 feet west of pumping station.
- Lockport.
- North of Joliet.
- South of Joliet.
- Ottawa.

Desplaines River:
- Lockport.

Kankakee River:
- Wilmington.

Illinois River:
- Morris.
- Ottawa.
- La Salle.
- Henry.
- Above Peoria.
- Below Peoria.
- Pekin.
- Havana.
- Beardstown.
- Kampsville.
- Grafton, 2 miles above mouth of Mis-sissippi River.

Fox River:
- Ottawa.

Vermilion River:
- La Salle.

Little Vermilion River:
- One sample every four wee

Sangamon River:
- Chandlerville.

Mississippi River:
- Grafton, above mouth o River.
- Alton, 100 feet from east ba
- Alton, east of midstream.
- Alton, midstream.
- Alton, west of midstream.
- Alton, 100 feet from west b
- Chain of Rocks, 400 yards nois shore.
- Chain of Rocks, main chan
- Chain of Rocks, inlet tower.
- Chain of Rocks, 400 feet souri shore.
- Jefferson Barracks, east ban
- Jefferson Barracks, east stream.
- Jefferson Barracks, midstre
- Jefferson Barracks, west stream.
- Jefferson Barracks, west ba

Missouri River:
- Fort Bellefontaine.
- Water tap at St. Louis.

The witness then gave the names of the samplers, descri methods of collecting and identifying the samples, and presen results of his examinations, together with those of D. B. Bis performed the chemical work in the department of health lab (4756–4764.) Herewith are reproduced the average results of nations made in the said laboratory of water taken from sampling points, July 3 to November 28, 1899. For more statements the reader is referred to pages 4770–4807 of the record.

Counsel for the defense directed the attention of the witnes results contained in the final column of Table 61, namely, the of bacteria per cubic centimeter, and in response to specific q concerning his interpretations the witness testified as follows

A comparison of the Illinois and Michigan Canal data at port with the Illinois River data at Averyville (above Peoria that there is a difference of 10 to 20 per cent in the number of present, and in some cases a difference of 100 per cent in favo Averyville samples, which show a much greater bacterial puri those collected at Bridgeport. The number of bacteria is fro 20 per cent less in the Averyville samples than in the Illin Michigan Canal samples, taken at Lockport, and in some ca difference amounts to 100 per cent, indicating a greater b

purity at Averyville. A comparison of the Illinois River samples at Morris with those at Bridgeport and at Averyville shows that the number of bacteria is not materially different in the Morris and Bridgeport samples, and that those at Averyville contain from 10 to 20 per cent of the number found at the other two points, indicating again a greater degree of bacterial purity. There is no material difference between the samples collected at Henry and those at Averyville, except in two instances, August 8 and September 30, when the bacteria were much higher at Henry. The bacterial counts at these two points are from 10 to 20 per cent of the number at Morris, showing much greater bacterial purity at these points than at Morris. The samples from Kankakee River at Wilmington show only slight differences in number of bacteria from the Illinois River samples at Averyville. In some instances the count is in favor of Kankakee River and in others in favor of Illinois River, the interpretation being that there is no material difference in the bacterial purity of these two waters. The number of bacteria in the Averyville samples is about equal to that in the tributaries of the Illinois, and the zone of self-purification extends down to about the location of Averyville. The results of examinations of Illinois River water at Wesley (below Peoria) and Pekin clearly indicate an increase of pollution in the stream between these two points, the bacterial purity at Averyville being greater than at either. A comparison of the bacterial counts of the Illinois and Michigan Canal at Lockport and of Illinois River at Wesley and Pekin shows approximately the same amount of bacterial purity. The Illinois River water at Grafton contains from 10 to 20 per cent of the number of bacteria found at Wesley and Pekin, and is therefore of far greater bacterial purity than the Wesley and Pekin waters. The bacterial counts at Grafton and Averyville are about the same. The bacterial purity of Mississippi River at Grafton is practically the same as that of Illinois River at Grafton. The samples from Illinois River at Grafton and from Missouri River at Fort Bellefontaine show no great difference in the bacterial content. The series of samples taken along the cross section in Mississippi River at Chain of Rocks shows practically the same bacterial counts at all points and indicates a general distribution of bacterial purity or impurity along the cross section. There is no material difference in the number of bacteria in the samples taken at Chain of Rocks, 400 feet from the Missouri shore, and in those 400 yards from the Illinois shore. The bacterial content of the samples taken along the cross section at Jefferson Barracks, below the outlet of the St. Louis sewers, is practically the same as that of the samples taken from the cross section at Chain of Rocks. (4808–4819.)

TABLE 61.—*Results of analyses of water made in the laboratory of the department of health of the city of Chicago from stated points, July 3 to November 28, 1899.*

[Parts per million.]

Sampling point.	Number of samples.	Turbidity.[a]	Sediment.[a]	Odor.	Residue.			Chlorine.	Oxygen consumed.			Nitrogen as ammonia.				Organic nitrogen.			Nitrogen as—		Number of times B. coli communis was present.	Bacteria per cubic centimeter.
													Albuminoid.									
					Total.	Dissolved.	Suspended.		Total.	Dissolved.	Suspended.	Free.	Total.	Dissolved.	Suspended.	Total.	Dissolved.	Suspended.	Nitrites.	Nitrates.		
Illinois and Michigan Canal at Bridgeport	17	VVH	M	Gassy	537	464	73	112	38	19	20	15.64	2.23	1.17	1.05	4	1.89	2.11	0.069	0.16	16	1,300,000
Illinois and Michigan Canal at Lockport	22	VVH	M	Gassy	543	426.7	70.5	115.7	39	20.5	18.9	14.53	2.59	1.40	1.19	4.33	2.37	1.96	.05	.16	17	650,000
Desplaines River at Lockport	22	VVS	VVS	None	359.5	348	14.5	8.8	11	10	.8	.07	.48	.43	.05	.83	.71	.13	.008	.26	16	170,000
Desplaines River above Joliet	22	VVH	M	Gassy	560	479	80.9	107.8	31.6	16.5	15	15.98	2.24	1.22	1.02	4.10	2	2.08	.038	.15	18	700,000
Desplaines River below Joliet	12	VH	H	Gassy	615	496.8	118.5	112.7	30.7	14	16.6	14.02	2.18	1	1.18	4.13	1.49	2.64	.027	.32	9	460,000
Kankakee River at Wilmington	22	H	VS	None	309	269	41.9	3.9	9	7	1.9	.054	.36	.28	.08	.76	.55	.24	.013	.69	11	23,000
Illinois River at Morris	21	M	S	None	419	405	16	72.9	15	11.9	3	10.05	1	.67	.34	1.76	1.18	.58	.083	.43	17	400,000
Fox River at Ottawa	21	VVS	VVS	None	308	292.8	20	6	7.9	7	.9	.06	.37	.34	.07	.69	.57	.16	.008	.32	7	14,500
Illinois River at Ottawa	21	VVS	VVS	None	400	386	15.6	65.5	10.9	10.5	1	5.67	.53	.47	.08	1.02	.93	.14	.57	1.57	16	43,500
Vermilion River at La Salle	22	S	S	None	1,173	1,134	40.9	109	5.3	3.9	15.5	.27	.27	.18	.09	.59	.39	.23	.024	.82	12	23,500
Illinois and Michigan Canal at La Salle	22	M	S	None	360.5	320	40	15	9.8	7	2.6	.52	.51	.39	.16	.98	.75	.23	.054	.46	17	110,000
Illinois River at La Salle	22	VS	S	None	417	386	32	57	11	9	1.8	3.42	.53	.41	.12	1.10	.89	.25	.51	1.84	18	41,000
Illinois River at Henry	21	S	M	None	413	382	32	53	11.7	9	2.6	2.2	.70	.42	.28	1.39	.88	.54	.45	1.60	15	56,000
Illinois River above Peoria	22	S	M	None	395	365	30	49	10	8	2.2	.79	.55	.36	.19	1.10	.80	.37	.39	1.75	17	24,000
Illinois River below Peoria	21	S	M	None	408	372	36.4	51	13	9.9	3.7	1.08	.86	.50	.36	1.59	1.01	.58	.45	1.67	10	2,100,000
Illinois River at Pekin	21	VS	S	None	393	365	28	48.3	11.7	9	2.6	.93	.69	.43	.26	1.40	.88	.51	.34	1.46	17	900,000
Illinois River at Havana	21	M	M	None	406	357	50	43	11	8.6	2.7	1.18	.62	.42	.20	1.29	.82	.49	.35	.90	18	100,000

Sangamon River at Chandlerville	16	M	M	None	304	203	93	5.6	6	3.5	2.7	.11	.33	.20	.13	.68	.30	.33	.03	.66	11	23,500
Illinois River at Beardstown	22	M	M	None	379	331	47	33.8	8.7	7.1	1.6	.85	.47	.33	.13	.97	.09	.29	.18	1.36	16	20,500
Illinois River at Kampsville	18	M	S	None	351	300	51.7	27.3	8.1	6.5	1.6	.25	.44	.29	.15	.92	.63	.30	.09	1.02	10	24,500
Illinois River at Grafton	21	H	VS	None	335	287	48	23.2	8.1	6.6	1.5	2.1	42	.30	.12	.83	.53	.28	.07	1.12	12	26,500
Mississippi River at Grafton	21	H	M	None	292	163	128	2.6	13.6	.65	3.8	.04	.44	.25	.18	.81	.46	.35	.004	.28	16	24,500
Mississippi River at Alton:																						
100 feet from Illinois shore	20	M	M	None	295	201	94	9	11.8	8.8	3	.06	.46	.27	.19	.88	.42	.41	.023	.42	16	30,000
One-fourth distance from Illinois shore	21	M	M	None	272	184	88	6.3	12.1	8.8	3.2	.037	.43	.27	.16	.77	.41	.38	.015	.31	15	26,000
Midstream	20	M	M	None	278	172	172	4.1	13	9.4	3.7	.028	.44	.27	.18	.81	.44	.38	.006	.25	13	26,500
One-fourth distance from Missouri shore	21	M	M	None	279	162	162	3	13.2	9.2	4	.04	.435	.25	.172	.79	.43	.79	.006	.24	12	19,500
100 feet from Missouri shore	20	M	M	None	264	161	161	3	13	9.3	3.7	.05	.43	.25	.18	.78	.44	.34	.005	.28	14	21,500
Mississippi River at Chain of Rocks:																						
400 yards from Illinois shore	21	VVH	VH	None	950	188	762	6.4	18	7.4	10.8	.049	.60	.23	.37	1.34	.43	.97	.009	.55	14	23,500
Midstream	21	VVH	VH	None	1,284	225	1,060	8.7	19.8	5.4	14.5	.05	.64	.162	.477	1.41	.31	1.1	.006	.48	16	150,000
Inlet tower	21	VVH	VVH	None	1,461	234	1,207	9.7	20.9	4.7	16.2	.046	.69	.14	.55	1.56	.30	1.22	.005	.56	17	27,500
400 feet from Missouri shore	21	VVH	VVH	None	1,584	243	1,341	10.7	21.8	4.14	17.7	.045	.70	.13	.57	1.58	.29	1.28	.004	.64	14	32,000
Missouri River at West Alton (Fort Bellefontaine)	19	VVH	VVH	None	1,479	275.7	1,089	13.75	17.3	2.3	14.1	.03	.56	.10	.46	1.33	.23	1.09	.003	.53	18	78,577
Mississippi River at Jefferson Barracks:																						
100 yards from Illinois shore	21	VVH	VVH	None	927.2	192.4	736	68.9	18.9	7.9	10.5	.053	.62	.21	.40	1.32	.38	.97	.015	.40	16	33,500
East of midstream	18	VVH	H	None	749.5	193.6	655	6.8	15.3	7.3	7.9	.37	.54	.22	.32	1.18	.38	.81	.009	.36	16	33,000
Midstream	21	VVH	VH	None	1,064.4	210	781	7.4	19.6	6.4	12.6	.042	.62	.20	.42	1.38	.35	1.03	.008	.46	17	29,500
West of midstream	18	VVH	VVH	None	1,043.1	236.8	806	9.2	15.7	5.3	10.3	.029	.55	.17	.38	1.30	.32	.98	.010	.47	14	43,500
100 yards from Missouri shore	21	VVH	VVH	None	1,271.3	236.9	1,034	10.3	18.7	4.9	13.7	.040	.65	.16	.49	1.45	.30	1.15	.009	.56	14	42,000
St. Louis tap water	18	VVH	VS	None	313	236.8	78	10.6	4.9	4	.9	.017	.17	.14	.03	.39	.29	.10	.005	.50	9	32,500

[a] H=heavy; VH=very heavy; VVH=very, very heavy; S=slight; VS=very slight; VVS=very, very slight; M=medium.

It should be noted in connection with the above testimon the witness was careful to use the term "bacterial purit made no reference to the pathogenic bacteria or disease-pr material, his conclusions being based solely on the number teria per cubic centimeter in the water, irrespective of their ch

The witness then testified that he had made examinations t mine the presence of the colon bacillus and the typhoid bacil that the results for the colon bacillus are recorded in the t which Table 61 is an average. The typhoid bacillus was not f any case. He further stated that he had found the *Bacillu giosus* during an examination of waters, but that he could n tively state from such a result that it occurred normally in the found in the vicinity of Chicago. His opinion was that it accidental entrance upon the culture plate, indicating th bacillus is occasionally present in the vicinity of Chicago and found by exposing suitable material for its growth. (4820–4

CROSS-EXAMINATION.

The first portion of the cross-examination was devoted to qu of procedure in the bacteriological examination of water, course of which the witness stated that a whole cubic centin water was very rarely used for the colony count, but the exami were made by diluting 1 c. c. with a portion of sterile wa calculating the result by multiplying the amount found u plate by the degree of dilution. The degree of dilution was d in samples from various portions of the river, some being dilu 100 and others 1 to 1,000, according to the amount of dilutio necessary by preliminary experience. (4852–4854.)

After this testimony the witness was asked whether or minute a quantity of water examined was sufficient to determi accuracy the bacterial condition of the whole canal or river point; to which he replied that it was not an exact demonstra the sense that a mathematical demonstration would be, but results that were comparable with other results reached simila at the same time, or in the same line of work. The bacteria simply gave an idea of the numbers of bacteria present, with erence to the kinds, and was not sufficient to indicate the po or unpotability of the water or the presence or absence of pat bacteria. All of this led up to questions concerning statement by the witness in his direct examination with reference to comp bacterial purity, and he explained that the term "bacterial pur not recognized as indicating the sanitary condition of a water ex far as the general activity of decomposition is concerned, wh a slight bearing on the question of purity or impurity. (4854-

The cross-examiner then led up to a discussion of the quality pollution of Lake Michigan water at various points and its ag

producing typhoid fever in Chicago. On the admission of the witness that it was his belief that this disease in the city was caused by the pollution of the water supply by the city sewage, the cross-examiner attempted to demonstrate from the testimony of the witness that inasmuch as Chicago sewage could pollute the water of the lake, a quiescent body, for distances so far from the shore as had been demonstrated, it was reasonable to believe that the pathogenic organisms of typhoid might exist for great distances in a running stream—even for a distance as great as that intervening between Chicago and St. Louis by way of Illinois and Mississippi rivers. The witness replied in general that Lake Michigan is by no means a quiescent body of water, being subject to currents due to winds and other natural phenomena, and that, in addition to this, Lake Michigan is a large body of comparatively pure water, which, according to his experience, is much more favorable for the preservation of the life of typhoid organisms than the more highly polluted water of the drainage canal and upper Illinois River. (4857–4865.)

ARTHUR W. PALMER.

DIRECT EXAMINATION.

Arthur W. Palmer, called as a witness in behalf of the defendants, stated that he had been for fifteen years professor of chemistry in the University of Illinois. He was educated in the public schools of Illinois and at Illinois, Harvard, Berlin, and Göttingen universities, where he had specialized in chemistry. He had paid particular attention to water analysis, having been engaged in that work as a student, teacher, and investigator for a period of twenty-two years. (4903–4904.)

The witness then related the facts concerning the agreement between the department of health of Chicago, the University of Chicago, and the University of Illinois with reference to the examination of samples of water from the Illinois River system. These facts are as related in the testimony of Prof. E. O. Jordan. (4904–4905.)

The witness then stated the location of the various sampling points included in the accompanying tables and described the surroundings and pertinent facts in connection therewith. (4905–4922.)

The method of handling samples, the determinations made, and their significance were then described by the witness. (4922–4938.)

Pages 4939 to 4976 of the record are occupied by tabular statements of examinations made at selected sampling points along the stream during the period from April 28 to December 27, 1899. The results of examination of samples collected between January 11 and October 8, 1900, appear on pages 4977 to 5026. The witness then described the significance of the various entries in these tables. (5027–5039.)

He then presented tabular statements of the average results of the series of determinations. These results are reproduced in Table 62. (5040, 5042.)

TABLE 62.—*Average results of analyses of water from Illinois and Mississippi river systems, at selected points, 1899 and 1900.*

[Parts per million.]

No. of station.	Sampling point.	Date.	Number of samples.	Residue on evaporation.							Oxygen consumed.			Nitrogen as ammonia.				Organic nitrogen.			Nitrogen.	
				Total.	Dissolved.	Suspended.	Loss on ignition. Total.	Loss on ignition. Dissolved.	Loss on ignition. Suspended.	Chlorine.	Total.	Dissolved.	Suspended.	Free.	Albuminoid. Total.	Albuminoid. Dissolved.	Albuminoid. Suspended.	Total.	Dissolved.	Suspended.	Nitrites.	Nitrates.
		1899.																				
1	Illinois and Michigan Canal at Bridgeport	Apr. 27-Dec. 26	22	584.1	499.7	85.4	65.1	39.5	25.9	124.2	35.1	17.9	17.2	17.16	2.513	1.158	1.355	4.985	2.282	2.703	0.025	0.295
2	Illinois and Michigan Canal at Lockport	Apr. 24-Dec. 26	31	572.6	495.4	77.2	60.8	44.7	25.1	120.1	37.7	18.7	19	15.58	2.681	1.147	1.534	5.072	2.373	2.699	.015	.23
3	Desplaines River at Lockport	do	33	370.8	355.3	15.5	46.1	39.8	6.3	8.47	11.9	10.3	1.6	.077	.467	.374	.093	.986	.776	.21	.007	.29
4	Desplaines River at Joliet	May 23-Dec. 26	30	568.8	484.4	84.4	60.9	39	21.2	105.7	28.5	16.2	12.3	14.92	2.195	.831	1.364	4.502	1.732	2.77	.01	.208
5	do	May 23-Sept. 11	17	601.6	460.1	141.5	65.9	42.6	23.3	99.8	31.4	16.2	15.2	12.794	1.962	.621	1.341	4.35	2.999	1.351	.009	.26
6	Kankakee River at Wilmington	June 5-Dec. 26	29	302.7	262.5	39.4	37.8	29.7	5.6	3.9	11.1	9.2	1.9	.047	.372	.266	.106	.886	.643	.245	.011	1.084
7	Illinois River at Morris	May 29-Dec. 26	25	410.5	381.1	17.6	43.1	36.6	6	65.7	14.9	12.2	2.7	8.897	.911	.539	.372	1.916	1.116	.8	.026	.537
8	Fox River at Ottawa	May 29-Dec. 28	30	344.8	295.8	49	52.8	46.7	7.4	5.84	9.9	8.3	1.7	.056	.416	.27	.146	.94	.550	.384	.008	.373
9	Illinois River at Ottawa	June 19-Dec. 28	27	395.2	379.9	15.3	41.2	35.7	5.6	59.4	11.3	10.6	1	4.995	.498	.399	.099	1.111	.824	.287	.497	1.62
10	Vermilion River at La Salle	May 24-Dec. 26	32	1,023.1	992.8	30.3	91.5	83.4	8.1	64.9	6.4	4.9	1.5	.254	.244	.159	085	.639	.400	.243	.022	.845
11	Illinois River at La Salle	May 5-Dec. 26	33	408.5	369.3	39.2	47.6	39.9	7.7	47.3	12.6	10.1	2.5	2.648	.503	.363	.14	1.216	.808	.408	.413	2.047
12	Illinois and Michigan Canal at La Salle	May 24-Dec. 26	32	367.6	331.8	35.8	51.2	44.9	6.3	16.95	10.9	8.5	2.4	.751	.499	.323	.176	1.244	.827	.417	.043	.62
13	Illinois River at Henry	May 30-Dec. 19	30	403.2	363.1	40.1	44.5	38.5	6	47.2	12.2	9.8	2.4	2.156	.594	.369	.225	1.382	.799	.583	.313	1.745
14	Illinois River at Averyville	May 1-Dec. 26	33	390.3	359.3	31	43.8	37.8	6	41.1	11.1	9.4	1.7	1.016	.49	.327	.163	1.143	.755	.388	.293	1.79
15	Illinois River at Wesley	May 29-Dec. 28	25	496.2	359.4	136.8	47.8	42.3	5.5	42.6	12.3	9.9	2.4	1.156	.91	.388	.303	1.603	.901	.702	.287	1.67
16	Illinois River at Pekin	May 24-Dec. 28	32	391.7	359.2	32.5	46.1	40.2	5.9	41.3	12.5	10	2.5	1.236	.681	.388	.293	1.532	.87	.662	.294	1.5
17	Illinois River at Havana	May 2-Dec. 20	33	386.5	343.9	42.6	42.4	36.6	5.8	35.8	12.1	9.6	2.5	1.203	.558	.36	.198	1.331	.816	.515	.227	1.12
18	Sangamon River at Chandlerville	May 31-Dec. 20	23	351.1	280.9	70.2	40.5	30	10.5	5.6	7.3	5	2.3	.115	.262	.154	.108	.72	.38	.34	043	.62
19	Illinois River at Beardstown	May 24-Dec. 28	29	383.4	318	65.4	35.6	32.5	5.7	30.4	10.8	8.3	2.5	.89	.443	.284	.159	1.09	.655	.435	.147	1.08
20	Illinois River at Kampsville	May 2-Dec. 20	33	382.6	281.6	101	37.4	29.3	8.1	20.1	10.5	7.99	2.51	.27	.409	.241	.168	1.065	.645	.42	.054	.97
21	Illinois River at Grafton	May 3-Dec. 27	34	349.5	274.7	74.8	38.7	29.7	9	18.5	9.9	7.8	2.1	.221	.412	.217	.165	1.03	.609	.428	.051	1.07
22	Mississippi River at Grafton	May 3-Dec. 20	33	342.4	153.1	189.3	36.1	26.7	9.4	2.6	15.8	10.8	5	.039	.499	.218	.251	1.142	.489	.653	.01	.295
	Mississippi River at Alton:																					
23	Illinois shore	do	34	351	197.6	153.4	34.3	25.1	9.2	8.2	13.4	9.9	3.5	.062	.454	.241	.213	1.117	.552	.565	.010	.57
24	One-fourth distance from Illinois shore	do	34	343.8	178.3	165.5	34.4	26.1	8.3	5.8	14.5	10.6	3.9	.053	.560	.23	.230	1.147	.525	.622	.014	.422

25	Midstream	do	34	381	104.5	216.5	39.3	27.5	11.8	3.7	15.2	10.6	4.6	.041	.498	.218	.28	1.207	.484	.723	.009	.355
26	One-fourth distance from Missouri shore	do	34	402.9	157.3	245.6	40.8	27.1	13.7	2.7	15.2	10.8	4.4	.031	.512	.219	.293	1.260	.487	.782	.007	.344
27	Missouri shore	do	33	399.8	158.5	241.3	41.5	28.9	12.6	2.6	15.4	10.9	4.5	.032	.505	.232	.273	1.223	498	.725	.009	.329
28	Missouri River at Fort Bellefontaine	July 8-Dec. 28	23	1,284.6	285.2	999.4	50.3	17.6	32.7	14.9	13.9	4.4	9.5	.03	.475	.102	.373	1.378	.272	1.106	.006	.337
	Mississippi River at Chain of Rocks:																					
29	Illinois shore	Apr. 28-Dec. 21	32	1,092.1	190.8	901.3	48.2	21.9	25.4	6	18.6	8.8	9.8	.039	.677	.201	.476	1.764	.45	1.314	.011	.442
30	Midstream	do	32	1,500.4	228.3	1,272.1	57.3	22.2	35.1	8	19.2	7.5	11.7	.027	.7	.162	.538	1.936	.383	1.553	.008	.387
31	Intake tower	do	32	1,109.6	232.8	876.7	60.2	20.6	39.6	9.1	19.5	6.8	12.7	.028	.726	.142	.584	2.174	.359	1.815	.007	.399
32	Missouri shore	do	32	1,909.3	247.1	1,662.2	61.8	19.9	41.9	9.8	19.9	6.2	13.6	.027	.817	.133	.684	2.358	.327	2.031	.007	.431
33	St. Louis tap water	June 6-Dec. 21	28	336	239.4	98.5	25.2	20	5.2	9.7	7.2	5.6	1.4	.022	.19	.125	.065	.57	.323	.247	.005	.342
	Mississippi River at Jefferson Barracks:																					
34	East shore	May 1-Dec. 21	31	1,104.9	196.2	908.7	49.8	24.3	26.3	6.2	19.1	8.6	10.5	.041	.682	.195	.487	1.789	.45	1.339	.01	.405
35	East of center	June 6-Dec. 21	28	1,174.6	197.1	977.5	53.8	22.5	31.3	6.4	19.9	8.6	11.3	.036	.678	.18	.498	1.852	.428	1.424	.008	.36
36	Center	May 1-Dec. 21	32	1,427.7	208.8	1,246.3	54.5	21.9	33.1	7	20.1	8.1	12	.031	.738	.175	.563	1.977	.396	1.581	.008	.366
37	West of center	June 6-Dec. 21	29	1,472.7	225.9	1,248.6	55.8	19.2	36.6	9	19.5	7.2	12.5	.031	.712	.151	.561	1.988	.338	1.65	.007	.367
38	West shore	May 1-Dec. 21	30	1,578	239.2	1,338.8	54.6	21.5	33.1	9.3	19.3	6.8	13	.037	.712	.143	.569	1.939	.356	1.583	.008	.35
		1900.																				
1a	Illinois and Michigan Canal at Bridgeport	Jan. 2-Oct. 8	29	449.3	405.8	43.5	38.8	26.6	12.2	118.5	17.7	9.5	8.2	10.614	1.632	.77	.862	3.466	1.436	2.025	.042	.296
1b	Sanitary canal at Kedzie avenue	Jan. 11-Oct. 8	51	212.8	172.1	40.7	25.6	18.3	7.3	14.2	9.8	4.9	4.9	1.247	.512	.176	.336	1.151	.398	.753	.015	.272
2	Illinois and Michigan canal at Lockport	Jan. 2-Sept. 24	36	518	451	67	42.7	30	12.7	135.2	20.7	11.1	9.6	13.4	1.814	.791	1.023	3.619	1.58	2.039	.016	.27
3	Sanitary canal at Lockport	Jan. 2-Sept. 28	58	264.6	241.5	23.1	30.6	24.7	5.9	12.3	8.9	6.5	2.4	9.986	.415	.232	.183	.918	.502	.416	.007	.39
4	Desplaines River at Joliet	Jan. 2-Oct. 8	41	265.2	231.9	33.3	29.8	22.4	7.4	30.4	11.1	7.3	3.8	2.971	.707	.402	.305	1.574	.83	.744	.031	.31
6	Kankakee River at Wilmington	Jan. 1-Sept. 27	34	334.4	259.5	74.9	38.4	31.8	6.6	3.3	11.3	8.2	3.1	.073	.371	.251	.12	.892	.567	.325	.014	2.208
7	Illinois River at Morris	Jan. 5-Sept. 25	39	287.7	237.2	50.5	29.5	23.9	5.6	23.5	10.4	6.7	3.7	2.374	.549	.275	.274	1.167	.635	.532	.1112	.761
8	Fox River at Ottawa	Jan. 4-Oct. 6	34	319.2	267.3	51.9	44.6	37.9	6.7	5.3	9.6	7.6	2	.13	.399	.251	.148	.816	491	.325	.008	.416
9	Illinois River at Ottawa	do	37	293.3	269.5	23.8	30.5	25.6	4.9	21.4	8.6	6.9	1.7	1.311	.39	.246	.144	.848	.537	.311	.51	1.624
10	Vermilion River at La Salle	Jan. 2-Oct. 2	40	480.7	409.9	70.9	52.3	42.8	9.5	16.4	7.3	4.8	2.5	.112	.259	.146	.113	.595	.314	.281	.018	3.522
11	Illinois River at La Salle	do	40	292.4	245.4	46.9	32	25.9	6.1	18.7	10.2	7.2	3	.963	.392	.251	.141	.944	.611	.333	.153	1.703
12	Illinois and Michigan Canal at La Salle	do	40	342.8	308.6	34.2	39.7	33.9	5.8	17.7	10.5	7.8	2.7	.944	.475	.327	.148	1.109	.697	.412	.049	1.005
13	Illinois River at Henry	Jan. 9-Oct. 1	37	293.3	243.8	49.5	31.9	25.1	6.8	16.7	9.9	7.2	2.7	.755	.4	.257	.143	.959	.572	.387	.118	1.551
14	Illinois River at Averyville	Jan. 2-Sept. 25	39	289.7	245.3	44.4	37.2	26.5	10.7	16.8	9.1	7.2	1.9	.653	.347	.233	.114	.781	.469	.312	.085	1.64
15	Illinois River at Wesley	Jan. 5-Oct. 3	38	325.1	246.4	78.7	34.9	26.2	8.7	17.5	10.1	6.9	3.2	.608	.386	.239	.147	.928	.547	.381	.07	1.535
16	Illinois River at Pekin	do	37	297.4	249.3	48.1	33.1	27.4	5.7	17.1	10.2	7.2	3	.672	.414	.244	.17	.924	.575	.349	.083	1.486
17	Illinois River at Havana	Jan. 11-Sept. 26	34	308	203.5	104.5	31.1	21.6	9.5	14.6	9.6	7.1	2.5	.616	.391	.235	.156	.921	.504	.417	.077	1.312
18	Sangamon River at Chandlerville	Jan. 3-Sept. 26	33	397.7	255	142.7	39.4	28.3	11.1	5	9.9	4.7	5.2	.107	.327	.146	.181	.783	.329	.454	.021	1.84
19	Illinois River at Beardstown	Jan. 4-Oct. 4	40	394.1	239.7	154.4	38.1	28.3	9.8	14.3	11.6	6.8	4.8	.507	.405	.236	.169	.966	.521	.445	.067	1.391
20	Illinois River at Kampsville	Jan. 3-Sept. 26	36	420.3	228	192.3	37.4	25.4	12	13.1	10.3	6.5	3.8	.394	.391	.208	.183	.97	.461	.509	.038	1.398
21	Illinois River at Grafton (see also below)	Jan. 4-Sept. 26	140	532	209.1	322.9	37.6	23.2	14.4	10.3	12.6	7	5.6	.401	.472	.233	.239	1.138	.481	.657	.021	1.426

TABLE 62.—*Average results of analyses of water from Illinois and Mississippi river systems, at selected points, 1899 and 1900*—Continued.

No. of station.	Sampling point.	Date.	Number of samples.	Residue on evaporation.						Chlorine.	Oxygen consumed.			Nitrogen as ammonia.				Organic nitrogen.			Nitrogen.	
							Loss on ignition.								Albuminoid.							
				Total.	Dissolved.	Suspended.	Total.	Dissolved.	Suspended.		Total.	Dissolved.	Suspended.	Free.	Total.	Dissolved.	Suspended.	Total.	Dissolved.	Suspended.	Nitrites.	Nitrates.
22	Mississippi River at Grafton (see also below)	Jan. 4-Sept. 28	90	440.8	150.5	290.3	39.9	23.8	16.1	3.78	15.8	8.9	6.9	.139	.537	.22	.317	1.208	.472	.736	.0076	.504
	Mississippi River at Alton:																					
23	Illinois shore	Jan. 4-Sept. 26	38	523.3	195.7	327.6	42.1	26.7	15.4	7.9	13.8	7.4	6.4	.269	.483	.212	.271	1.138	.477	.661	.017	1.063
24	One-fourth distance from Illinois shore	Jan. 4-Sept. 25	35	495.4	182.8	312.6	42.9	25.1	17.8	7.1	14.7	7.6	7.1	.259	.508	.196	.312	1.198	.434	.764	.014	.896
25	Midstream	Jan. 4-Sept. 26	37	418.3	161.1	257.2	40.7	25.1	15.6	4.8	15.3	8.8	6.5	.21	.514	.205	.309	1.15	.434	.716	.01	.56
26	One-fourth distance from Missouri shore	Jan. 4-Sept. 25	36	449.8	155	294.8	38.2	24	14.2	4.1	15.6	8.1	7.5	.175	.535	.21	.325	1.188	.433	.755	.01	.525
27	Missouri shore	Jan. 4-Sept. 26	38	436.3	154.7	281.6	39.1	23.5	15.6	4.1	15.2	9	6.2	.157	.507	.211	.296	1.144	.468	.676	.009	.535
28	Missouri River at Fort Bellefontaine	Jan. 4-Oct. 9	40	1,866.6	266.1	1,600.5	67.5	19	48.5	16.1	18.6	4.9	13.7	.092	.875	.134	.741	2.279	.325	1.954	.0072	.662
	Mississippi River at Chain of Rocks:																					
29	Illinois shore	Jan. 5-Oct. 4	61	769.7	180.3	589.4	44.7	23.6	21.1	6.86	15.9	7.8	8.1	.153	.542	.193	.349	1.288	.403	.885	.008	.698
30	Midstream	do	61	1,062.9	194.4	868.5	50	23.6	26.4	7.88	17.9	7.6	10.3	.115	.665	.181	.484	1.561	.411	1.15	.005	.579
31	Intake tower	do	61	1,545.9	215.3	1,330.6	57.5	20.5	37	10.9	19.6	6.1	13.5	.116	.774	.152	.622	1.938	.327	1.611	.005	.593
32	Missouri shore	Jan. 5-Oct. 1	59	1,406	241.2	1,164.8	55.1	20.9	34.2	13.3	19.7	4.9	14.8	.107	.825	.134	.691	2.131	.297	1.834	.005	.629
33	St. Louis tap water	Jan. 4-Oct. 4	40	340.9	243.6	97.3	28.1	20.6	7.5	11.9	7.5	5.7	1.8	.039	.205	.193	.012	.551	.309	.242	.005	.647
	Mississippi River at Jefferson Barracks:																					
34	East shore	Jan. 4-Apr. 20	15	671.4	185.4	486	38.6	18.6	20	7.02	15.2	7.6	7.6	.313	.631	.211	.42	1.545	.508	1.007	.017	1.016
35	East of center	do	14	653.4	187.7	465.7	39.4	19.6	10.8	7.6	14.9	7.5	7.4	.262	.604	.201	.403	1.463	.505	.958	.017	.963
36	Center	do	15	780.2	198.4	581.8	41	20.9	20.1	8.7	16	7.3	8.7	.302	.597	.232	.365	1.529	.475	1.054	.016	.853
37	West of center	do	14	977.6	268.8	688.8	38.4	17.5	20.9	11.7	15.7	7	8.7	.257	.685	.192	.493	1.611	.489	1.122	.015	.797
38	West shore	do	15	1,013.6	246.8	766.8	35.8	16	19.8	13.5	15.6	6.3	9.3	.242	.612	.178	.434	1.541	.409	1.132	.015	.76
21	Illinois River at Grafton	Jan. 4-Sept. 26	39	434.6	229.1	209.5	38.5	27.3	11.2	12.47	10.9	6.6	4.3	.37	.403	.205	.198	.931	.478	.453	.024	1.362
22	Mississippi River at Grafton	do	38	365	151.4	213.6	37.3	23.1	14.2	3.5	15.1	8.8	6.3	.111	.465	.216	.249	1.075	.453	.622	.007	.445

The witness then presented tables containing the averages of determinations made during the periods from June to September, inclusive, for 1899 and 1900, respectively, and following these read into the record two other tables showing, first, the average of determinations made during the four months, June to September, inclusive, 1899 and 1900, of samples taken from Illinois River at Grafton, Mississippi River at Grafton, and Missouri River at Fort Bellefontaine, together with the highest and lowest determinations during these periods at each of the points mentioned, also the averages for the same four-month periods for samples from a few other selected points; second, a similar statement based on all the determinations during the two years. (5047–5054.)

Evidence was then presented concerning the determination of dissolved oxygen in an extensive series of samples taken under special conditions from specified points in the canal and rivers under discussion. The determinations were made according to the Winkler and the Levy methods, and the results appear in a table occupying pages 5062–5068 of the record. The period covered by these examinations extended from the latter part of April, 1899, to the middle of October, 1900. With reference to the remark, "Test of keeping qualities," placed at certain points in the table, the witness explained that although most of the determinations were made on the spot at the time of collection it was desired to procure some information as to the changes taking place in the organic matter of the water during transportation from the sampling point to the laboratory. Therefore duplicate samples were taken, one being treated immediately and the other being reserved for a period varying from twelve hours to two days, after which the determination was made. Inasmuch as samples of waters containing organic matter suffer a loss of dissolved oxygen when they are allowed to stand out of their natural environment, a great diminution is regarded as an indication of inferiority in the water as compared with one in which the diminution is slight. In the samples so noted in the table the stability of the organic matter, or, in other words, the "keeping qualities" of the water, are indicated. (5055–5061.)

With reference to the results of the dissolved-oxygen determinations, the witness made the following statements: Illinois River water contains at all times a considerable percentage of the oxygen required for saturation, and at times is supersaturated. The supersaturation is due to the liberation of oxygen by chlorophyl-bearing organisms in the water. Samples shipped to the laboratory before being treated nearly always contained an amount of oxygen less than the amount of saturation, though those treated with mercuric chloride showed no diminution. It is certain that the actual content of dissolved oxygen

expressed in the results is in many cases considerably less than the actual amount.

The witness then discussed these results in narrative form, calling attention to the various interpreting features. As these features are clearly apparent to the careful reader of the table they will not be repeated here. (5070–5079.)

Three diagrams were then presented and discussed, showing graphically the changes taking place in each of the constituents determined in samples of water taken from the established points hereinbefore designated during the two periods of investigations, 1899 and 1900. These diagrams merely show in another form the relations presented in Table 62 and therefore are not reproduced here. (5080–5097.)

The witness then introduced a series of plates, numbered 4 to 15, inclusive, showing graphically the average proportions of some of the more significant constituents of the waters of Illinois, Mississippi, and Missouri rivers, so that the conditions during similar periods in 1899 and 1900 might readily be compared. These plates are not here reproduced, because the facts that they are alleged to show may readily be taken from Table 62. (5097–5147.)

A series of tables containing the results of examinations made by the witness as director of the State water survey of Illinois was then presented. These analyses include weekly samples taken from the following points:

Lake Michigan at Chicago, 1897–1900.
Illinois and Michigan Canal at Lockport, 1897–1901.
Chicago drainage canal at Lockport, 1900–1901.
Desplaines River at Lockport, 1897–1901.
Desplaines River at Joliet (east and west sides), 1901.
Illinois River at Morris, 1897–1900.
Illinois River at Ottawa, 1899–1901.
Illinois River at La Salle, 1897–1900.
Illinois River at Averyville, 1897–1901.
Illinois River at Havana, 1897–1900.
Illinois River at Kampsville, 1897–1902.
Illinois River at Grafton, 1899–1902.
Mississippi River at Grafton, 1899–1901.
Mississippi River at Alton, 1897–1900.
Mississippi River at Quincy, 1897–1903.
Kankakee River at Wilmington, 1897–1900.
Fox River at Ottawa, 1898–1901.
Spoon River at Havana, 1897–1899.

These tables, with the subsequent explanations and reiterations for purposes of evidence, occupy pages 5166–5360 of the record. Averages of the results appear in Table 63.

The witness discussed the above results in part as follows: Up to the opening of the Chicago drainage canal the water in the old Illinois and Michigan Canal varied in character but little from year to year, but a great change followed the opening of the drainage canal. The relative proportion of organic matter in the old canal was greatly reduced, although the free ammonia became greater owing to the more speedy oxidation of the organic matter facilitated by the dilution. The proportions of ingredients in the water of the drainage canal show notable variations, due to various apparent causes, but the data show that the sewage discharged from the canal is far more dilute than that formerly discharged through the old Illinois and Michigan Canal. (5371–5372.)

After noting the changes in the character of the water, as shown by the determinations in Table 63, from the canals at Lockport down to Averyville, the witness stated that it was "highly probable" that the organic substances introduced at Chicago had been completely destroyed by the time the water reached Averyville, and that the organic matter remaining was of vegetable rather than of animal origin. The averages of the Averyville determinations show that the water at this point contains considerably less organic matter than is present in the water of the comparatively unpoluted tributary streams. (5388–5389.)

Calling attention to the averages of the Havana samples, the witness stated that enormous discharges from the distilleries and cow pens at Peoria and Pekin had created in the stretch of 45 miles of river lying between these two points and Havana what was practically an immense septic tank. This stretch of the river, especially the upper part, had been very offensive. Nevertheless, so active had been the natural processes of purification that at Havana the water was in practically as good condition as at Averyville, above the point of entrance of this pollution. The records after the opening of the drainage canal show, according to the witness, a greatly reduced proportion of organic constituents. (5392–5393.)

The testimony of the witness, found on pages 5394–5451 of the record, was devoted to a review of the data given in Table 63. The variations shown were narrated and the figures presented in manifold ways and groups, both tabular and diagrammatic. As nothing was added by way of evidence or deduction, beyond that which is readily apparent in Table 63, no digest of this portion of the testimony will be made.

TABLE 63.—*Averages of results of analyses of samples of water from designated streams at specified points and dates.* (5362-5393).

[Parts per million.]

Sampling point and date.	Chlorine.	Oxygen consumed.			Nitrogen as ammonia.				Organic nitrogen.			Nitrogen as -	
		Total.	Dis-solved.	Sus-pended.	Free.	Albuminoid. Total.	Dis-solved.	Sus-pended.	Total.	Dis-solved.	Sus-pended.	Nitrites.	Nitrates.
Illinois and Michigan Canal at Lockport:													
1896	119.1	39.2	14.7	24.5	14.99	2.55	1.17	1.38	5.17	2.19	2.98	0.007	0.195
1897	115.4	38.3	18.1	20.2	12.4	2.72	1.34	1.38	4.94	2.31	2.63	.039	.338
1898	116.8	42.2	19.1	23.1	12.7	2.86	1.48	1.38	5.52	2.5	3.02	.072	.417
1899	135.2	39.5	21.2	18.3	13.9	2.93	1.44	1.51	5.56	2.84	2.72	.013	.217
Average	121.6	39.8	18.3	21.5	13.5	2.77	1.36	1.41	5.3	2.46	2.84	.033	.292
1900	135	21	11.5	9.5	12.6	1.77	.77	1	3.62	1.51	2.11	.022	.272
1901	133.2	18.8	13.7	5.1	17.6	1.16	.7	.46	2.18	1.45	.73	.025	.208
Average		19.9	12.6	7.3	15.1	1.47	.735	.73	2.9	1.48	1.42	.023	.24
Chicago drainage canal at Lockport:													
1900	15.6	7.65	5.12	2.53	1.593	.421	.183	.238	.985	.442	.543	.006	.237
1901	14.5	9.29	6.76	2.53	1.715	.422	.238	.184	.99	.532	.58	.023	.183
Average	15	8.47	5.94	2.53	1.654	.421	.210	.211	.987	.486	.5	.015	.21
Desplaines River at Joliet:													
1899	105.7	28.5	16.2	12.3	14.92	2.195	.831	1.364	4.502	1.732	2.77	.01	.208
1900	30.4	11.1	7.3	3.8	2.971	.707	.402	.305	1.574	.83	7.44	.031	.31
1901 (east side)	29.7	9.7	7.4	2.3	3.335	.478	.269	.209	1.05	.574	.476	.031	.334
1901 (west side)	14.7	8.6	6.7	1.9	1.629	.359	.218	.141	.871	.515	.356	.03	.268
Average	22.2	9.1	7.0	2.1	2.492	.418	.243	.175	.96	.544	.416	.03	.296
Illinois River at Morris:													
January to December, 1896	29.7	14.5	.....	.....	3.55	.709	.....	.....	1.44	.....	.....	.149	1.72
January to December, 1897	45.7	15.9	10.3	5.6	5.78	.862	.46	.402	1.608	.895	.71	.15	1.097
January to September, 1898	34.7	17.3	.....	.....	4.109	1.398	.....	.....	2.491	.....	.....	.016	.196
May to December, 1899	65.6	14.7	12.1	2.6	8.9	.911	.59	.372	1.915	1.115	.8	.026	.553
Four years average	44.4	15.6	11.2	4.1	5.585	.97	.499	.387	1.8625	1.05	.756	.0965	1.0665
1900	23.1	12.3	6.7	5.6	2.075	.535	.269	.266	1.162	.631	.531	.108	.717
Fox River at Ottawa:													
March to December, 1898	7.93	9.3	7.1	2.2	.064	.407	.288	.119	.823	.553	.27	.027	.471
May to December, 1899	5.84	9.9	8.3	1.6	.055	.416	.27	.146	.94	.555	.385	.008	.373
January to October, 1900	5.3	9.6	7.5	2.1	.129	.399	.251	.148	.815	.491	.324	.008	.416
Average	6.36	9.6	7.63	1.96	.083	.407	.27	.137	.86	.533	.326	.014	.42

Illinois River at Ottawa													
June to December, 1899	30.5	11.3	10.5	1.13	4.09	.498	.309	.069	1.111	.824	.287	.496	1.847
January to October, 1900	21.3	8.6	6.9	1.7	1.311	.30	.244	.147	.848	.537	.311	.25	1.62
July to October, 1901	28.5	6.6	5.8	.8	.97	.223	.173	.05	.898	.508	.39	.454	1.209
Illinois River at La Salle:													
January to December, 1896	19.6	12.3	9.04	3.26	.971	.612	.429	.183	1.260	.98	.28	.255	2.51
January to December, 1897	30.9	13.1	9.6	3.5	1.728	.6	.384	.216	1.234	891	.343	.442	2.14
January to December, 1898	25.9	11.2	8.4	2.8	1.396	.488	.357	.131	1.158	.721	.437	.25	9.55
February to December, 1899	44.7	13.6	10.4	3.2	2.536	.482	.379	.103	1.285	.807	.478	.385	1.955
Four years average	30.28	12.55	9.36	3.19	1.658	.5455	.387	.158	1.234	.852	.386	.333	1.89
1900	18.7	10.1	7.2	2.9	.963	.391	.251	.141	.944	.611	.333	.152	1.7
Illinois River at Averyville:													
April to December, 1897	37.9	11.3	9.4	1.9	.843	.503	.367	.136	1.01	.794	.216	.254	1.69
April to December, 1898	21.4	9.3	7.5	1.8	.86	.403	.316	.087	.83	.646	.184	.124	.807
April to December, 1899	47.2	12.9	9.4	3.5	1.025	.494	.325	.169	1.11	.722	.388	.204	1.558
Three years average	30.2	11.1	8.76	2.4	.909	.466	.336	.13	.98	.72	.262	.194	1.351
1900	17.5	8.4	6.6	1.8	.639	.323	.226	.101	.767	.534	.233	.079	1.584
1901	17.5	7.7	6.7	1	.647	.249	.198	.051	.717	.575	.141	.081	1.337
Two years average	17.5	8.05	6.6	1.4	.643	.286	.212	.076	.742	.555	.187	.08	1.46
Illinois River at Havana:													
1896	15.1	10.9	.....	.....	.63	.49	.....	.....	1.17	.....	.....	.174	2.34
1897	24.8	10.8	9.6	1.2	.893	.46	.41	.05	.988	.717	.271	.203	1.66
1898	19.6	9.3	7.5	1.8	.95	.43	.32	.11	.92	.683	.237	.121	.809
1899	27.3	13.3	9.8	3.5	1.104	.56	.35	.21	1.303	.788	.515	.163	1.133
Four years average	21.7	11.1	8.97	2.16	.894	.485	.365	.12	1.095	.729	.341	.155	1.485
Three years average (1897–1899)	23.9	11.1	8.97	2.16	.982	.484	.365	.12	1.071	.729	.341	.162	1.2
1900	14.8	8.7	6.8	1.9	.585	.361	.23	.131	.839	.533	.306	.07	1.308
Illinois River at Kampsville:													
1897	19.3	10.9	7.7	3.2	.351	.509	.303	.206	1.024	.691	.333	.08	1.553
1898	12.6	11.7	6.8	4.9	.372	.484	.278	.206	1.018	.579	.439	.069	.764
1899	16.5	12.4	8.2	4.2	.392	.473	.257	.216	1.129	.623	.506	.052	.988
Three years average	16.1	11.7	7.5	4.1	.371	.488	.279	.209	1.057	.631	.426	.069	1.101
1900	14.1	11.5	6.1	5.4	.382	.36	.206	.154	.904	.481	.423	.038	1.436
1901	15.6	9.4	7.2	2.2	.375	.338	.218	.12	.999	.579	.42	.044	1.221
1902	10.2	11.3	8.1	3.2	.424	.349	.23	.119	.....	.....	.....	.039	1.219
Three years average	13.3	10.7	7.1	3.6	.393	.349	.218	.131	.951	.53	.421	.04	1.292

The witness then presented a diagram showing the relative proportions of upper Mississippi River water and Illinois River water at five points in a cross section of Mississippi River, 16 miles below the mouth of Illinois River and 7 miles above the mouth of Missouri River, calculated from the average chlorine content at those points as determined from weekly analyses throughout 1899 and 1900. From this diagram it appears that in 1899 the average chlorine in Mississippi River above Grafton was 2.9 parts per million and in the Illinois above Grafton 15.2 parts. At the cross section above mentioned the water at the Missouri shore contained 3.2 parts, equivalent to 2.4 per cent of Illinois River water. At one-fourth the distance from the Missouri shore the water contained 3.5 parts of chlorine, equivalent to 4.8 per cent of Illinois River water. In midstream there were 4.3 parts of chlorine, equivalent to 11.3 per cent of Illinois River water. At three-fourths the distance from the Missouri shore, or one-fourth the distance from the Illinois shore, there were 5.8 parts of chlorine, equivalent to 23.5 per cent of Illinois River water, while at the Illinois shore there were 7.5 parts of chlorine, equivalent to 38 per cent Illinois River water. The record for 1900 was given as follows:

Average chlorine in Mississippi River water above Grafton, 3.1 parts per million; in Illinois River water above Grafton, 13.1 parts. Proportions and percentages at the five points in the cross section, taken in the same order as for 1899, 3.5 parts, equivalent to 4 per cent Illinois water; 4.1 parts, or 10 per cent; 4.4 parts, or 13 per cent; 7.1 parts, or 40 per cent; 7.6 parts, or 46 per cent.

From these figures the witness expressed the opinion that the waters of Mississippi and Illinois rivers were by no means commingled by the time they reached the mouth of Missouri River. (5452–5454.)

The witness then expressed the opinion that there is no satisfactory basis on which a calculation of the relative proportions of water from Mississippi, Illinois, and Missouri rivers entering the intake at Chain of Rocks could be made, but for all such calculations the chlorine determination would be the most satisfactory, because chlorine is not, like the various forms of nitrogen, a variable constituent. It would not be practicable to determine these proportions from free ammonia or from nitrites because the amounts of these constituents change by reason of decomposition processes going on within the water. The comparative proportions of total solids might be used for this purpose if the amounts in the three waters differed sufficiently, but even then errors would arise because total solids include both dissolved and suspended matter. Variations in the amount of solids in suspension, caused by variations in velocity of flow or in character of material underlying the stream bed and constituting the banks, would take place without any corresponding changes in the amount of water contributed by the stream. Estimates of proportional contribution based on suspended matter would be unsatisfactory for the same reason. (5452–5457.)

Further testimony of the witness, occupying pages 5459–5511, inclusive, comprised the narration of chemical facts given in Table 63, together with amplifications of the same, accompanied by diagrams. Included in this part of the testimony were diagrammatic representations of the stages of water in Illinois, Mississippi, and Missouri rivers, scaled in with coincident analytical records, the purpose of which was to show that increase in the determinations, such as total organic nitrogen, free and albuminoid ammonia, etc., were the result of or were attended by increased flow in the rivers, and were not caused by increase in polluting material. The witness believed that the fact that these changes took place in the water of Mississippi and Missouri rivers as consistently as in that of the Illinois was important evidence that the apparently unfavorable changes in the composition of the Illinois water were not the result of pollution from the Chicago drainage canal. In other words, he was of the opinion that such pollution had not changed the character of the water of Mississippi River at Chain of Rocks. (5511–5512.)

The witness offered in evidence the results of analyses of special cross-section samples taken as follows:

Illinois River at Averyville, July 21, 1899, and November 26, 1901.
Illinois River at Wesley, July 22, 1899.
Illinois River at foot of Terminal Bridge [Pekin], November 26, 1901.
Illinois River below Pekin, November 26, 1901.
Illinois River at Grafton, January 5, and July 28, 1899.
Mississippi River at Grafton, January 5 and 18, February 15, May 24, and July 28, 1899.
Mississippi River at Hartford, July 7 and August 17, 1900.
Mississippi River at Chain of Rocks, April 14 and December 7, 1899.
Mississippi River at Alton, December 6, 1899.

He then made the following statements: At Averyville the waters are substantially uniform in quality throughout the entire section. At Wesley the waters are not uniform, the greatest amount of pollution being near the west shore. The same is true at the Terminal Bridge. Substantially uniform conditions prevail throughout the cross sections in Illinois River at Grafton. The waters of Illinois and Mississippi rivers are not perfectly commingled at Hartford, that of the Illinois persisting mainly along the Illinois shore. The cross-section samples at Mitchell, 2 miles below the mouth of Missouri River, show that the three bodies of water remain distinct. (5515–5525.)

Pages 5532–5558 of the record contain the analytical results of further examinations made during October, November, and December, 1901, of samples taken from the following points:

Illinois River at Averyville.
Illinois River at Pekin.
Illinois River at Grafton.
Mississippi River at Grafton.
Missouri River at Fort Bellefontaine.
Mississippi River at Chain of Rocks (Illinois shore, midstream, intake tower, and Missouri shore).

Concerning the figures the witness stated that the waters of the three rivers—Mississippi, Illinois, and Missouri—show great differences, and that water from the Illinois is deflected toward the eastern shore of the Mississippi and only small proportions of it come into immediate contact with water from the Missouri. In total oxygen required the waters from the three rivers rank from highest to lowest in the following order: Missouri River, Mississippi River, Illinois River. In oxygen required by matter in solution they rank from highest to lowest in the following order: Mississippi River, Illinois River, Missouri River. Comparison of the results from the three rivers in 1901 with results in 1899 showed improvement in the Mississippi and Illinois River waters and deterioration in the Missouri River water. (5559–5563.)

With reference to the amount of organic matter in the water of Illinois River before and after the opening of the drainage canal, the witness stated that the results of determinations of organic nitrogen by the Kjeldahl process on samples taken from Illinois River at Kampsville during 1897 to 1902, inclusive, showed an average of 1.087 parts per million before the opening of the canal and 0.8966 part per million afterwards. This represents a decrease of 17.48 per cent. Similar data for dissolved organic nitrogen showed a decrease of 17.92 per cent for the three years after the opening of the canal. During the same period there was 25 per cent decrease in the albuminoid ammonia, 6 per cent increase in free ammonia, 40 per cent decrease in nitrites, and 15.67 per cent increase in nitrates. (5567–5573.)

The witness then entered into a long and very much involved discussion of the amounts of organic nitrogen discharged into Desplaines River during the years immediately before and subsequent to the opening of the canal, and the persistence of the same downstream. Numerous tables were given, showing amounts in tons, etc., all of which made an interesting and clever discussion of the nitrogen question, but can hardly be said to be particularly relevant to the case at hand. The matter occupies pages 5575–5627 of the record.

In closing his direct testimony the witness drew the following conclusions:

First. The opening of the Chicago drainage canal improved the condition of the water in Illinois River all along its course.

Second. The waters of the Illinois above its mouth, of the Mississippi above the mouth of the Illinois, and of the Missouri above its confluence with the Mississippi are unfit for drinking purposes in the raw state.

Third. The discharge of sewage from the Chicago drainage canal does not injuriously affect the water of the Mississippi along the eastern border of the State of Missouri, but, on the contrary, the influx of pure water from Lake Michigan into Illinois River has caused a more complete destruction of the organic matter from Chicago sewage than under former conditions, when said sewage was discharged through the Illinois and Michigan Canal. (5640–5643.)

CROSS-EXAMINATION.

With reference to the accuracy and significance of his analytical work on the streams of Illinois, the witness presented the following opinions:

The analyses placed in the record throw much light on the sanitary condition of the water, but do not directly determine the absence or presence of disease organisms. They do, however, show the presence or absence of sewage, and therefore indicate the possible presence or absence of substances which as a class are objectionable in drinking waters for the reason that they themselves or the substances which accompany them are deleterious to health when introduced into the system through drink. "The basis for the detection of the presence and the kind and the characteristics of the disease-producing organisms and substances which in sewage and waters at times accompany the chemical constituents found in these fluids rests mainly upon the various chemical reactions and decompositions which said organisms and substances produce and the chemical substances which result from their action." Without a recognition of the significance of the chemical changes which disease-producing organisms bring about, there would be no means of determining their presence in running water, but this branch of the science is called bacteriology. (5644–5647.)

The substances whose presence and proportion are shown by the ordinary sanitary analysis include those which serve as the food supply of micro-organisms, together with the substances of which those micro-organisms, both the good and the bad, are made up. Chemistry does determine the harmful substances or the toxins, but in ordinary analytical work no practicable method is known for separating these substances and determining their proportions. The chemist can distinguish between those nitrogenous organic matters that are of a proteid character and serve as a food supply for micro-organisms and other nitrogenous organic matters that are not proteid in character, but are the products of vital processes, such as toxins. (5650–5652.)

With reference to the frequency of the determinations, the witness said:

While it is always desirable to have as many analyses as is possible, and even more than the number which I made for, say, * * * Kampsville, practical reasons * * * prevented my making more * * * during the periods covered in my testimony, and it is my opinion that the evidence * * * submitted covers the case reasonably well. * * * The water of Illinois River at Kampsville has not been at other times during the period in question materially different from the condition revealed by the analyses which I have submitted in evidence. * * *

It is quite possible, in the opinion of the witness, that different samples taken at the same point at the same time and by the same collector would show a material difference in chemical constituents when analyzed by different chemists, but the averages of a considerable number of such samples would not be materially different, although no table of averages would give a correct representation of the water in this stream at all times. (5660–5661.)

The witness stated that the analytical methods used by Professor Jordan of the University of Chicago, by Mr. Bisbee of the Chicago health department, and by himself were substantially the same. (5658–5659.)

The following questions and answers appear on pages 5663–5666 of the record:

Q. Professor, referring to Table No. 20, of the series of Tables 1 to 80, inclusive, introduced and read in evidence by yourself, and to Table 178, being tables introduced by the defendants and known as defendants' tables of streams examinations, 1 to 196, which constitute a part of the testimony of Mr. Bisbee, we find upon comparison of these tables that during the month of September, 1899, there were samples collected by the water takers at that point, and these samples are known in the evidence of these water takers as companion samples, one of each of which was shipped to you and the other shipped to Mr. Bisbee, and of these samples you analyzed four, the analyses of which were made by you September 7, September 14, September 21, and September 28; and of these samples Mr. Bisbee analyzed three, to wit, September 7, September 14, and September 21. These samples were collected on the 6th, 13th, 20th, and 27th days of September, 1899. Upon your determination of the chemical constituents of those samples, you found that on September 7 to contain 1.0 of organic nitrogen; of the samples analyzed on the 14th of September you found 0.84 of organic nitrogen, and of the sample analyzed on the 21st of September you found 1.0 of organic nitrogen, and the sample examined by you on the 28th of September you found 0.82 of organic nitrogen. Mr. Bisbee in his analyses found contained in the sample analyzed by him on September 7, total organic nitrogen, 0.60; that analyzed on the 14th of September, organic nitrogen, 1.04, and that analyzed by him on the 21st day of September, total organic nitrogen, 0.76, no analyses having been made by him of the sample collected on the 27th of September so far as organic nitrogen was concerned. All these samples were taken from the Illinois River at Kampsville. Now, do not these analyses show upon comparison a material difference with reference to the constituent known as total organic nitrogen in the waters of the Illinois River at Kampsville for the month of September, 1899, comparatively speaking?

A. They do not, in my opinion, show a substantial difference in the content of total organic nitrogen in the water of the Illinois River at Kampsville during the month of September, 1899, for the reason that they are, in my opinion, partly the result of differences in the details of the method used in the determination of the total organic nitrogen, although the method employed was in general the same in both cases, that is, in the analyses made by Mr. Bisbee and those made by myself, and for the further reason that the averages for the month—that is, the average proportion for the three analyses made by Mr. Bisbee—namely, those made upon samples collected upon the 6th, the 13th, and the 20th of September, 1899, respectively, and those made by me upon samples collected upon the same days in the same month of 1899, which samples were collected simultaneously with those analyzed by Mr. Bisbee, for I find that the average for the three determinations made by Mr. Bisbee were 0.8 part per million, the average for the three samples analyzed by me corresponding to the three examined by Mr. Bisbee were 0.95, a much less difference than is indicated between certain of the individual determinations included in these six analyses.

Q. I will ask you, Professor, if that difference, taking the average difference between the examinations made by Professor Bisbee and those made by yourself, does not amount to 18.8 per cent, counting yours as 100 per cent, or as being accurate?

A. Assuming as the basis for the calculation my own average, 0.95, the difference between the two averages is 15.78 per cent, while taking Mr. Bisbee's average of 0.8 as the basis of the calculation the difference is 18.75 per cent.

Q. Now, may not these same differences of 40 per cent, 23.8 per cent, and 24 per cent have occurred, even though you had made the analyses in both instances, for the month of September instead of having been made one by yourself and the other by Mr. Bisbee?

A. In my opinion they would not.

Q. Is it a fact that Mr. Bisbee's results are always higher or lower than yours, or do they not vary first one way and then the other?

A. So far as I am aware they vary in both directions, some of them being higher and some of them being lower than my own.

Q. Now I will ask you, Professor, if it is not a fact that a comparison of the analytical results of the samples of water collected in September, 1899, at Kampsville and examined by yourself and by Professor Bisbee do not show either a very rapid change in the chemical condition of that water or do not show extensive variations, chemically speaking, in the water at that time and place and even on the dates and at the hour of collecting the samples?

A. In my opinion, these variations in the results of the analyses do not indicate similarly considerable variations in the actual content of the total organic nitrogen in the water samples collected at the same date and hour, nor do they show rapid variations in these substances contained in the water; but, in my opinion, the variations in the determinations as recorded in the tables you have quoted are very largely the result of differences in the details of the method employed in making these determinations, to which I have referred in my answer to the preceding question.

Q. Do those variations—to wit, variations comparatively speaking, shown between the analyses made by yourself and those made by Mr. Bisbee—result from differences in accuracies or differences in inaccuracies?

A. Doubtless they are in part due to both; but in my opinion in the main they are due to variations in the details of the processes to which I have referred in my answers to the two preceding questions.

No allowance had been made in reporting the analytical presented in the evidence of the witness for errors resulti changes in organic matter during the period of transit from s point to laboratory, because the conditions governing these were similar throughout the six-year period. Consequen changes as had occurred would affect all the samples, and the basis of comparison of the first half with the last half of sa would not be affected. The variations arising from consi sample taken at any time as representative of the water in t stream are, in the opinion of the witness, eliminated in a long analyses, and a series of results is afforded that may be c strictly comparable. (5680–5683.)

Q. Professor, assuming that there is discharged into the Illinois River, the drainage canal, the sewage from the city of Chicago, which contains c isms which produce typhoid fever; assuming that those organisms are of a acter and that they live in the sewage of Chicago, the drainage canal, and the Illinois River from five to thirty days or more, disappearing by death from five to thirty days or more, until at the end of thirty days or more all h innocuous; assuming further that they flow down the canal to the Illinois the water and with the same velocity as the water in the canal and the riv that the mean velocity from Chicago to St. Louis is eighteen days; assu average life of these organisms has expired at some point between Averyvil ton, but assume also that, as heretofore stated, the extreme life limits will in thirty days or more to a point far below St. Louis. State whether or n averages upon the life limit of these organisms, which shows that such a place at some point in the river between Averyville and Grafton, can b sanitarian or by a sanitary chemist as proof, from a practical sanitary stan no such disease-producing organisms pass a given point between Averyvil ton and do not reach the St. Louis intake at the Chain of Rocks and pass city of St. Louis.

A. It, in my opinion, can not; but the conditions prevailing in the Missi between Grafton and the Chain of Rocks as to the mixing of the waters in with the waters of the Mississippi and the waters of the Missouri render it, in highly improbable that any considerable proportion of such pathogenic g be contained in the waters of the Illinois at Grafton—that is, if we grant the of the question—passes down the Mississippi to the point below, St. Louis, into the intake of the St. Louis waterworks. (5694–5697.)

THOMAS J. BURRILL.

DIRECT EXAMINATION.

Thomas J. Burrill, called as a witness in behalf of the defendants, stated that he had graduated from the Illinois State Normal University in 1863, having specialized in biology, and that since that time he had been engaged continuously in botanical studies, especially cryptogamic. He had been teaching botany at the University of Illinois for thirty-five years and at the date of testimony was professor of botany there. He had lectured before different societies in this country and in England and had received the degrees of M. A., Ph. D., and LL. D. He had made numerous official water studies in the State of Illinois. (5711–5716.)

Beginning in May, 1899, the witness made a series of bacteriological examinations of samples from selected points on Illinois River and tributaries, including the Chicago drainage canal, in collaboration with Professors Palmer and Jordan. The results of these examinations are set forth in Table 64. (5724–5725.)

In introducing the above results, the witness stated that the decrease in the number of bacteria between Morris and Ottawa is out of all proportion to that which would be caused by the dilution received from tributary streams, indicating that there has been a considerable degree of purification. The decrease is maintained to Averyville, where the number equals that of ordinary river water not subject to contamination, proving that the pollution from Chicago has practically disappeared. The same is true at Grafton. The figures further show that there is practically no difference in bacteriological purity between the waters of Illinois River above Grafton and of Mississippi River above Grafton, but that the water from Missouri River at Fort Bellefontaine has greater contamination than the other two. The witness could not state probable causes, but noted that the temperature of Missouri River was lower than that of the Mississippi, which had something to do with the lessened rate of decrease—that is, in lowering the activity of the bacteria that destroy the organic matter. (5748–5749.)

The witness then gave the results of his tests for *Bacillus coli communis* during June, July, August, and September, 1899 and 1900. The figures in Table 65 are based on the diagrams, page 5754, and there may be some small errors due to incorrect reading of the scales. They are probably not significant, however.

TABLE 64.—*Monthly averages of determinations of the number of bacteria per cubic centimeter in samples of water taken at designated points.*

Sampling point.	Year.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.
Drainage canal at Kedzie avenue	1900	.....	.....	.....	.....	1,474,000	377,000	863,888	1,233,700	1,186,665	.....	.....	.....
Illinois and Michigan Canal at Bridgeport	1899	.....	.....	.....	.....	.....	1,035,500	3,895,555	.....	2,483,333	2,150,000	2,497,000	2,151,666
Do	1900	3,862,000	6,063,333	4,240,000	6,037,500	.....	.....	.....	1,215,000	315,000	.....	.....	.....
Illinois and Michigan Canal at Lockport	1899	.....	.....	.....	.....	.....	3,885,750	5,323,750	3,215,000	696,666	1,335,000	582,000	746,250
Do	1900	2,256,000	.....	4,405,000	3,891,250	1,649,000	997,500	731,250	790,000	3,290,000	.....	.....	.....
Desplaines River at Lockport	1899	.....	.....	.....	.....	.....	14,912	11,162	38,850	24,160	25,783	9,640	16,300
Do	1900	42,370	.....	167,500	21,375	5,647	40,162	.....	.....	.....	.....	.....	.....
Drainage canal at Lockport	1900	.....	.....	.....	.....	.....	.....	601,250	1,205,666	651,666	.....	.....	.....
Desplaines River at Joliet	1899	.....	.....	.....	.....	.....	1,445,000	2,848,666	3,220,000	217,000	1,145,000	1,023,000	1,026,250
Do	1900	973,000	1,448,333	2,000,000	1,655,000	485,000	18,000	170,000	134,750	203,330	.....	.....	.....
Desplaines River south of Joliet	1899	.....	.....	.....	.....	.....	1,369,375	3,201,666	4,611,666	985,000	.....	.....	.....
Kankakee River at Wilmington	1899	.....	.....	.....	.....	.....	22,837	4,720	4,000	5,387	11,075	11,650	25,300
Do	1900	5,790	102,000	75,250	52,000	3,300	3,650	950	1,975	4,950	.....	.....	.....
Illinois River at Morris	1899	.....	.....	.....	.....	.....	999,875	930,750	4,882,375	2,186,100	505,000	747,000	170,000
Do	1900	2,737,500	1,731,250	1,593,750	392,500	46,200	246,125	42,375	76,600	624,750	.....	.....	.....
Illinois River at Ottawa	1899	.....	.....	.....	.....	.....	20,550	9,298	7,512	40,100	33,050	18,070	261,766
Do	1900	256,250	228,000	116,750	68,500	15,125	14,237	2,950	18,830	34,875	.....	.....	.....
Fox River at Ottawa	1899	.....	.....	.....	.....	.....	11,027	3,670	4,560	4,822	5,475	5,900	7,000
Do	1900	12,275	.....	84,166	49,250	5,800	2,412	3,266	2,962	9,375	.....	.....	.....
Illinois River at La Salle	1899	.....	.....	.....	.....	.....	17,800	6,370	11,875	9,700	27,112	11,910	101,400
Do	1900	192,400	278,750	367,666	96,125	13,050	12,275	3,500	13,000	17,412	.....	.....	.....
Illinois and Michigan Canal at La Salle	1899	.....	.....	.....	.....	.....	170,050	157,766	241,000	166,375	131,250	164,400	223,000
Do	1900	193,300	169,625	212,000	157,750	25,300	31,062	38,375	17,200	73,775	.....	.....	.....
Vermilion River at La Salle	1899	.....	.....	.....	.....	.....	7,062	4,510	1,480	3,102	3,987	14,050	12,757
Do	1900	13,750	45,912	103,125	33,000	22,270	8,550	5,475	7,000	2,200	.....	.....	.....
Illinois River at Henry	1899	.....	.....	.....	.....	.....	64,350	22,362	26,350	11,100	8,575	5,880	59,966
Do	1900	41,462	160,500	183,625	39,875	14,260	3,487	40,433	1,850	136,700	.....	.....	.....
Illinois River at Averyville	1899	.....	.....	.....	.....	.....	8,700	9,358	4,000	3,100	3,768	1,640	9,300
Do	1900	27,570	129,500	93,375	13,087	15,920	1,637	4,233	8,060	4,466	.....	.....	.....
Illinois River at Wesley	1899	.....	.....	.....	.....	.....	1,476,480	3,925,000	2,355,000	484,575	2,373,750	705,000	20,666
Do	1900	89,000	95,666	107,750	22,750	70,400	58,625	96,000	99,250	264,375	.....	.....	.....
Illinois River at Pekin	1899	.....	.....	.....	.....	.....	1,500,000	737,625	1,928,333	391,250	1,047,500	812,000	69,000
Do	1900	128,100	84,000	125,125	27,250	100,500	150,625	313,375	286,500	1,061,875	.....	.....	.....
Illinois River at Havana	1899	.....	.....	.....	.....	.....	6,816	5,950	5,725	6,137	12,433	159,040	301,333
Do	1900	124,166	79,575	181,875	26,500	23,850	15,000	24,125	21,362	50,662	.....	.....	.....
Sangamon River at Chandlerville	1899	.....	.....	.....	.....	.....	7,125	9,900	19,783	20,300	3,683	7,100	10,266
Do	1900	10,620	101,433	105,875	13,625	11,850	29,562	13,900	4,450	4,316	.....	.....	.....
Illinois River at Beardstown	1899	.....	.....	.....	.....	.....	4,400	1,350	10,287	3,039	5,000	26,070	114,100
Do	1900	239,750	420,500	145,750	28,375	12,880	7,962	4,275	15,000	5,550	.....	.....	.....
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5,065	28,850

Mississippi River at Alton:														
100 feet from Illinois shore	1899						2,475	1,242	3,319	3,612	2,575	9,600	23,750
Do	1900	20,470	86,500	119,750	18,125	17,620	13,125	3,266	3,180	6,687			
One-fourth distance from Illinois shore	1899						6,087	809	2,355	3,000	2,112	17,630	22,533
Do	1900	18,940	98,125	175,000	46,625	18,180	7,875	4,800	6,180	5,500			
Center of channel	1899						5,775	2,021	2,455	3,725	2,425	7,160	18,300
Do	1900	23,380	105,125	166,250	66,000	26,000	4,375	6,966	6,710	8,200			
One-fourth distance from Missouri shore	1899						5,725	1,753	2,647	2,525	2,375	6,390	8,416
Do	1900	19,040	88,500	149,875	48,500	16,040	6,750	9,050	5,640	6,400			
100 feet from Missouri shore	1899						7,250	2,927	2,215	2,562	2,200	5,730	4,183
Do	1900	18,620	104,100	144,875	85,500	24,080	5,875	3,862	7,610	4,433			
Mississippi River at Chain of Rocks:													
400 yards from Illinois shore	1899						19,706	5,737	11,700	5,325	3,075	5,037	9,816
Do	1900	35,087	113,100	98,166	17,500	21,800	14,875	26,191	6,110	4,357			
Center	1899						12,883	6,830	15,850	12,063	11,775	25,075	15,183
Do	1900	70,075	95,150	97,000	60,125	34,200	21,625	24,250	8,725	13,310			
Inlet tower	1899						18,100	6,275	20,437	14,737	14,462	26,612	31,650
Do	1900	76,525	66,800	125,833	58,375	31,300	23,750	27,045	13,300	9,170			
400 yards from Missouri shore	1899						16,650	5,902	32,275	9,250	10,187	30,125	25,233
Do	1900	64,925	50,300	143,333	57,500	64,125	25,375	29,275	10,256	12,927			
Missouri River at Fort Bellefontaine	1899							20,000	32,695	23,417	16,325	28,510	10,475
Do	1900	84,960	40,066	179,750	77,000	66,200	63,375		12,450	25,187			
Mississippi River at Jefferson Barracks:													
East shore	1899						66,250	10,050	87,825	69,250	59,500	5,750	6,133
Do	1900	19,750	97,500	130,875	54,666								
East of center	1899						37,475	13,400	45,712	43,750	33,625	9,000	9,241
Do	1900	24,460	136,500	145,375	25,500								
Center	1899						41,100	6,962	29,837	18,787	11,833	11,600	6,675
Do	1900	28,720	79,666	129,750	48,333								
West of center	1899						55 350	5,737	54,525	42,125	45,250	25,900	19,087
Do	1900	44,460	79,750	130,500	56,500								
West shore	1899						33,637	12,050	63,125	60,125	52,875	22,562	16,350
Do	1900	23,500	61,666	154,750	55,333								
St. Louis tap	1899						14,392	851	810	1,990	1,710	8,952	2,433
Do	1900	4,865	8,233	10,137	5,233	6,300	2,625	1,650	1,950	10,125			
Chicago tap	1900		2,425	850	750	140	88	96	95	213			

TABLE 65.—*Identification of Bacillus coli communis in Illinois and Mississippi rivers and tributary streams, 1899–1900, by percentage of total tests.*

Sampling point.	Per cent positive.	
	1899.	1900.
Desplaines River at Joliet	100	45
Kankakee River at Wilmington	37	58
Illinois River at Morris	71	33
Illinois River at Ottawa	43	20
Fox River at Ottawa	30	22
Illinois and Michigan Canal at La Salle	90	46
Vermilion River at La Salle	43	40
Illinois River at La Salle	40	13
Illinois River at Henry	27	31
Illinois River at Averyville	23	17
Illinois River at Wesley	100	88
Illinois River at Pekin	91	87
Illinois River at Havana	50	46
Sangamon River at Chandlerville	27	36
Illinois River at Beardstown	45	47
Illinois River at Kampsville	45	64
Illinois River above Grafton	17	53
Mississippi River above Grafton	30	38
Mississippi River at Alton	26	45
Missouri River at Fort Bellefontaine	.....	62
Mississippi River at Chain of Rocks	91	74

In discussing the diagrams, the witness pointed out that *Bacillus coli communis* was found more frequently in Missouri River at Fort Bellefontaine than in Illinois River above Grafton, and somewhat less frequently in Mississippi River above Grafton than at either of the other two places. The least number of positive results was found at Averyville. (5756.)

The witness then gave the following results of examinations made during October to December, 1901. (5761–5769.)

TABLE 66.—*Average results of examinations of water from designated points, October to December, 1901.*

Sampling point.	Average number of bacteria per cubic centimeter.	Per cent B. coli communis.
Illinois River at Averyville	13,691	6.2
Illinois River at Pekin	299,000	7.6
Illinois River above Grafton	8,441	10.7
Mississippi River above Grafton	5,407	11.5
Missouri River at Fort Bellefontaine	127,353	57.1
Mississippi River at Chain of Rocks (average of four points)	63,402	41.1
Illinois shore	52,177	21.7
Midstream	43,185	50
Intake tower	127,862	36.3
Missouri shore	32,845	57

The witness then stated that the conclusions to be drawn from the above results are the same as those from the series of 1899 and 1900. He pointed out that the cross-section samples at Chain of Rocks show that the pollution is least at the Illinois shore and increases to the Missouri shore. (5773.)

The witness then stated that the sewage of Chicago does not produce any effect on Mississippi River. (5774–5775.)

CROSS-EXAMINATION.

From experiments made on the longevity of *Bacillus prodigiosus* the witness had come to the conclusion that the germ does not persist in water for a great length of time, especially when associated with water bacteria. He had never observed them to live longer than five days. (5792.)

No further new facts were brought forward in the cross-examination of Professor Burrill.

EDWIN OAKES JORDAN.

DIRECT EXAMINATION.

Edwin Oakes Jordan, called as a witness in behalf of the defendants, qualified by stating that he was associate professor of bacteriology at the University of Chicago and had been connected with that university in various positions from associate through the various grades to his present appointment. He graduated from the Massachusetts Institute of Technology in 1888 and then studied for a time at the College of Physicians and Surgeons in New York. After this he was for nearly two years in the employ of the Massachusetts State board of health in connection with work being done at the Lawrence experiment station. Subsequent thereto he went to Clark University, at Worcester, Mass., where he received the degree of doctor of philosophy. He remained there until he went to Chicago in 1892. During his term of service at the Lawrence experiment station he had charge of the bacterial work and was familiar with the chemical work, having received training therein at the Massachusetts Institute of Technology. He had taught public hygiene at the University of Chicago for several years, and in lectures on that subject had been obliged to deal with the classic epidemics of this country and abroad; he had also studied several epidemics at first hand. He was at Lowell for a short time with Professor Sedgwick during the typhoid epidemic there, and since had visited Stamford, Conn., where there had been an epidemic of typhoid fever, attributed to infected milk. More recently he had visited Ithaca, N. Y., and examined the watershed of the stream which was the source of water supply for that town. He had given considerable attention to what is known as bacteriological sanitary science, including epidemiology and water chemistry. (5805–5807.)

In connection with his work on Illinois River he stated that there were three periods of investigations, one extending from April, 1899, to the end of the year; the second from January 1 to the end of June,

1900, and the third from October, 1901, to January 1, 1902. These investigations included samples from the Illinois and Michigan Canal; the Chicago drainage canal; Illinois River and its branches, the Desplaines, Kankakee, Fox, Vermilion, and Sangamon; Mississippi and Missouri rivers, and Lake Michigan. The location of the sampling stations which were maintained during these investigations will be indicated in the tabular statement of analytical results. (5807–5809.)

The third series of investigations at designated points was undertaken by agreement with the authorities of the State of Missouri. Branch laboratories were established under direction of the witness at Peoria, Grafton, and St. Louis. That at Peoria was in charge of F. W. Schule, that at Grafton in charge of W. S. Sayer, and that at St. Louis in charge of E. E. Irons and W. G. Sackett. All four of these men qualified in testimony. They sent in written reports of their work at weekly intervals, keeping duplicate copies of these reports on file at the separate laboratories. The greater part of the work was carried on in the laboratory of the University of Chicago by the witness with the assistance of Prof. F. L. Stevens and by W. G. Sackett and E. E. Irons, except during the periods when they were engaged in the branch laboratories. The witness stated that in selecting the men to take samples at the various stations a special effort had been made to obtain the services of trustworthy persons. Full directions and instructions were given to these men, a reproduction of which appears on pages 5811–5812 of the record. The witness then related the various methods of procedure and discussed the determinations. The routine work in the bacteriological analysis consisted of a determination of the number of bacteria capable of forming colonies upon a nutrient agar plate and a determination of the relative abundance of the *Bacillus coli communis*. (5809–5814.)

The witness then gave the results of the determinations made in the first and second periods, the evidence being read into the record in tables designated from 81 to 158, inclusive. (5818–5950.)

The average results of these examinations are given in Table 67. (5958–5959.)

The witness then gave his interpretations of the results of the analyses in the series of 1899 as follows:

The water in the Illinois and Michigan Canal at Bridgeport and Lockport, as well as that of Desplaines River at Joliet and of Illinois River at Morris, contains a large amount of nitrogenous organic matter in the early stages of decomposition. The high proportion of chlorine indicated the greatest pollution during the period cited; also the large amount of bacteria present in the samples showed that there were in the water substances capable of serving as food for this great abundance of organisms. The tables further show that at Ottawa

a very great change has taken place in the composition of the river water, due to dilution from Kankakee River as well as to oxidation and sedimentation. This change is manifested especially by the diminution in the amount of albuminoid ammonia, the increase in the amount of nitrites and nitrates, and particularly by the enormous diminution in the bacterial content. This purification continues with the passage of the river downstream, and by the time the water reaches Averyville its character has so improved that its quality is comparable with ordinary surface waters in the United States, and especially with that of the tributaries of Illinois River. (5819-5845.)

Below Averyville the analyses show the influence of the large influx of polluting material from Peoria and its stockyards and distilleries, evidenced by the increase in albuminoid and free ammonia and in the number of bacteria. Additional pollution is shown in the Pekin samples, but from this point to the mouth of the river the purification follows a generally progressive course until at Grafton the amount of free and albuminoid ammonia and the oxygen consumed, the number of bacteria, and the relatively high amount of nitrites all bear witness to the practically complete oxidation of the enormous amount of organic matter with which the river water is laden at Lockport and Peoria. (5847-5859.)

Concerning the analyses made in 1900 the witness stated that the samples taken from the Chicago drainage canal showed considerable dilution as compared with the water in Chicago River. Examination of the analyses of samples of water from Illinois River at Morris showed that the river is charged with a large amount of organic matter, as is evidenced by the large amount of nitrogen in the form of albuminoid and free ammonia, by the oxygen consumed, and by the high number of bacteria. Considerable purification is shown by the Ottawa samples, all the ammonia and oxygen consumed determinations being smaller and the number of bacteria being a little more than one-fourth of the number in the river water at Morris during the same period. At Averyville a still greater purification is shown; the same polluting influences at Peoria and Pekin as in 1899 are apparent in this series, and, finally, a nearly complete purification is shown in the determinations at Grafton. The self-purification of Illinois River during the whole period 1899-1900 is noticeable in character and extent, both at high and low water and at high and low temperature, and shows convincingly that under the conditions prevailing in the Illinois Valley the self-purification of streams "is not an interesting biological myth but an actual and definite occurrence." (5963-5965.)

TABLE 67.—*Average results of analyses of water from Illinois and Mississippi river systems at designated points, 1899–1900.*

[Parts per million.]

Sampling point.	Date.	Residue on evaporation.			Chlorine.	Oxygen consumed.			Nitrogen as ammonia.				Nitrogen as—		Bacteria, per cubic centimeter.
		Total.	Dissolved.	Suspended.		Total.	Dissolved.	Suspended.	Free.	Albuminoid. Total.	Albuminoid. Dissolved.	Albuminoid. Suspended.	Nitrites.	Nitrates.	
Illinois and Michigan Canal at Bridgeport	April-December, 1899	562.7	481.8	80.9	119.2	30.3	15.2	15.1	15.9	2.64	1.25	1.39	0.016	0.166	1,245,000
Do	January-April, 1900	421.8	389	33	96.6	16.6	9.57	7.03	8.05	2.05	1.04	1.05	.0214	.074	631,000
Illinois and Michigan Canal at Lockport	May-December, 1899	562	485.1	76.9	117.4	32.1	17.5	14.6	15.7	2.42	1.29	1.13	.002	.18	650,000
Do	January-June, 1900	491	451.8	39.4	124.5	18.1	11.1	6.8	10.9	2.07	.962	1.15	.0133	.0664	1,755,000
Desplaines River at Lockport	May-December, 1899	371	353.4	17.6	7.9	10.1	8.8	1.3	.072	.452	.378	.074	.011	.167	9,380
Do	January-June, 1900	363.8	334	29.7	6.1	9.08	7.8	1.1	.143	.384	.291	.007	.0138	.3467	12,500
Desplaines River at Joliet (above town)	May-December, 1899	561	480.1	80.9	104.8	25.4	14.4	11	14.7	2.12	.97	1.15	.007	.12	492,000
Do	January-June, 1900	307	274	32	41.5	10.4	7.1	3.3	4.22	.833	.474	.359	.0215	.086	744,286
Kankakee River at Wilmington	June-December, 1899	307.4	271.3	36.1	3.4	8.5	7	1.5	.054	.352	.290	.062	.010	.733	5,000
Do	January-June, 1900	343.8	268	76	2.9	9.4	7.2	2.13	.099	.327	.222	.106	.174	1.58	16,100
Illinois River at Morris	May-December, 1899	413.1	394.2	15.9	68.1	13.2	8.9	4.3	9.33	.863	.533	.330	.025	.31	400,600
Do	January-June, 1900	313	242.8	73	24.46	9.6	6.8	3.2	2.458	.599	.315	.24	.075	.424	445,000
Fox River at Ottawa	May-December, 1899	345	297.7	47.3	4.99	8.3	5.9	2.4	.074	.470	.280	.190	.010	.26	6,500
Do	January-June, 1900	326.7	264	62	3.9	8.97	6.87	2.1	.111	.42	.262	.158	.0136	.345	20,600
Illinois River at Ottawa (above town)	June-December, 1899	395.8	380.6	15.2	58.5	9	7.4	1.6	4.17	.503	.381	.122	.37	.98	27,470
Do	January-June, 1900	320	292	28	15.3	8.5	6.9	1.59	1.555	.414	.277	.1366	.197	.966	116,000
Big Vermilion River at La Salle	May-December, 1899	996.6	957.3	39.3	61.2	4.9	3.6	1.3	.224	.247	.153	.094	.017	.57	7,970
Do	January-June, 1900	441	353	87	10.1	6.4	3.8	2.5	.1	.285	.12	.164	.044	.227	19,200
Illinois River at La Salle	May-December, 1899	417.6	368.1	49.5	46.1	9.4	7.7	1.7	27.72	.496	.364	.132	.32	1.38	8,870
Do	January-June, 1900	307.7	250.9	56.9	17.5	9.06	6.95	2.1	1.046	.4228	.258	.164	.109	.979	94,000
Illinois River at Henry	May-December, 1899	399.1	370.1	29	44.2	9.9	7.7	2.2	2.008	.548	.376	.172	.255	1.12	13,290
Do	January-June, 1900	306	250	52	13.26	8.8	6.9	1.9	.916	.378	.235	.142	.102	.8	64,200
Illinois and Michigan Canal at La Salle	May-December, 1899	375.6	336.1	39.5	15.6	8	6.3	1.7	.715	.454	.311	.143	.042	.62	49,580
Do	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.447	.289	.159	.0658	.88	54,600

Illinois River at Havana	May-December, 1899	390.4	343.7	40.7	36.2	8.6	6.9	1.7	1.235	.520	.353	.176	.194	.87	17,470
Do	January-June, 1900	303	243	58	11.2	7.5	6.07	1.38	.597	.361	.218	.142	.065	.57	23,100
Sangamon River at Chandlerville	May-December, 1899	335.1	267.2	67.9	4.52	5.5	3.4	2.1	.052	.239	.149	.090	.020	.61	5,080
Do	January-June, 1900	409	260	148	4.75	7.6	3.92	3.68	.096	.308	.135	.174	.020	1.32	24,200
Illinois River at Beardstown	May-December, 1899	385.6	326.9	58.7	20.3	7.6	5.9	1.7	.83	.528	.301	.127	.151	.81	14,080
Do	January-June, 1900	460	249	196.1	10.7	10.7	6.28	4.4	.691	.441	.217	.224	.106	.685	28,200
Illinois River at Kampsville	May-December, 1899	369.3	296.8	72.5	22.9	7.4	5.6	1.8	.309	.425	.262	.163	.075	.76	4,810
Do	January-June, 1900	500.5	233	266	11.3	9.8	5.9	3.9	.659	.445	.195	.25	.044	.87	33,700
Illinois River at Grafton	May-December, 1899	473.1	385.1	88	18.3	7.8	6	1.8	.253	.400	.257	.143	.044	.71	10,210
Do	January-June, 1900	503	240	260	9.8	9.8	5.7	4.1	.463	.423	.1931	.2299	.031	1.06	21,000
Mississippi River at Grafton	May-December, 1899	407.3	165.8	241.5	2.8	12.7	8.6	4.1	.082	.492	.226	.266	.005	.24	7,600
Do	January-June, 1900	444	155	247	5.3	13	7.6	5.45	.123	.522	.177	.346	.007	.3	30,600
Mississippi River at Alton:															
East bank	May-December, 1899	353.2	202.4	150.8	7.6	10.4	7.3	3.1	.076	.417	.249	.168	.042	.45	7,900
Do	January-June, 1900	587	204	371	7.2	10.9	6.1	4.8	.242	.489	.171	.318	.0165	.69	30,300
East of center	May-December, 1899	326.2	182.9	143.3	5.4	11.4	8	3.4	.....	.442	.236	.206	.026	.33	7,720
Do	January-June, 1900	535	178	357	5.8	12.1	6.5	5.6	.251	.509	.173	.336	.013	.65	47,000
Midstream	May-December, 1899	379.2	164.9	214.3	3.7	11.5	8.4	3.1	.054	.465	.228	.237	.008	.28	6,650
Do	January-June, 1900	508	162	346	4.9	13.2	7	6.6	.224	.528	.187	.34	.01	.429	51,800
West of center	May-December, 1899	412	168	244	2.7	12.6	7.7	4.9	.047	.482	.222	.260	.004	.23	6,350
Do	January-June, 1900	499	155	348	4.6	13	6.9	6.3	.194	.544	.174	.365	.0098	.396	55,200
West bank	May-December, 1899	391.2	163.8	227.4	2.74	11.9	7.7	4.2	.041	.498	.241	.257	.005	.26	7,760
Do	January-June, 1900	489	153	336	4.3	13	6.6	6	.159	.495	.179	.316	.0102	.379	42,500
Missouri River at Fort Bellefontaine	July-December, 1899	1,124.5	294.7	829.8	15.4	8.7	2.9	5.8	.035	.377	.079	.298	.002	.27	8,170
Do	January-June, 1900	1,736	294	1,446	15.4	13.9	3.7	10.1	.065	.754	.111	.643	.0066	.56	43,100
Mississippi River at Chain of Rocks:															
East bank	May-December, 1899	1,203.1	198.6	1,004.5	5.1	14.5	6.8	7.7	.057	.697	.199	.498	.011	.42	12,480
Do	January-June, 1900	917	199	723	6.7	13.7	6.2	7.4	.211	.586	.16	.426	.0151	.58	36,200
Midstream	April-December, 1899	1,612.2	224.8	1,387.4	7	15.6	5.8	9.8	.048	.744	.159	.586	.005	.34	12,390
Do	January-June, 1900	1,269	209	1,055	8.6	14.8	5.7	9.1	.145	.697	.138	.559	.0096	.43	46,600
Intake tower	April-December, 1899	1,945.9	246.4	1,699.5	7.8	15.7	5.5	10.2	.051	.806	.147	.659	.002	.35	12,920
Do	January-June, 1900	1,626	227	1,399	10.3	14.7	5.4	9.3	.117	.679	.125	.574	.0845	.38	41,000
West bank	April-December, 1899	1,993.2	240.8	1,752.4	8.8	15.3	4.6	10.7	.049	.904	.139	.765	.003	.37	11,960
Do	January-June, 1900	2,056	265	1,791	12.8	14.9	4.1	10.7	.081	.714	.106	.608	.0083	.46	49,700
St. Louis tap water	June-December, 1899	342.2	251.6	90.6	8.8	5.8	4.6	1.2	.024	.168	.126	.042	.003	.37	2,330
Do	January-June, 1900	351.6	254	101	13.4	6	4.4	1.6	.028	.196	.12	.075	.0052	.4	7,760
Mississippi River at Jefferson Barracks:															
East bank	May-December, 1899	1,228.1	202.2	1,025.9	5.6	15	6.5	8.5	.048	.744	.188	.556	.005	.35	17,590
Do	January-April, 1900	686	194	492	7.2	12.6	6.3	5.8	.263	.612	.179	.435	.016	.76	65,600
East of center	June-December, 1899	1,311.7	205.1	1,106.6	5.8	15	6.3	8.7	.045	.729	.190	.539	.006	.37	13,120
Do	January-April, 1900	722	189	533	7.2	12.9	6.05	6.9	.285	.639	173	.447	.015	.6	59,700
Midstream	May-December, 1899	1,502.2	215.4	1,286.8	6.4	15.2	5.9	9.3	.049	.710	.163	.547	.004	.34	13,320
Do	January-April, 1900	837	197	641	8.4	12.8	5.8	7	.223	.607	.167	.44	.013	.565	69,500
West of center	June-December, 1899	1,633.1	233.3	1,399.8	7.9	14.9	4.9	10	.048	.686	.143	.543	.003	.51	21,850
Do	January-April, 1900	1,077	227	857	11.3	12.8	5	7.7	.206	.647	.1605	.486	.012	.53	74,800
West bank	May-December, 1899	1,792.5	232.6	1,559.9	8.2	15.8	4.8	11	.058	.838	.148	.690	.005	.43	25,180
Do	January-April, 1900	1,087	248	776	12.6	12.3	4.7	7.5	.259	.608	.139	.468	.012	.48	69,900

TABLE 67.—*Average result of analyses of water from Illinois and Mississippi river systems at designated points, 1899–1900*—Continued.

Sampling point.	Date.	Residue on evaporation.			Chlorine.	Oxygen consumed.			Nitrogen as ammonia.				Nitrogen as—		Bacteria, per cubic centimeter.
		Total.	Dissolved.	Suspended.		Total.	Dissolved.	Suspended.	Free.	Albuminoid. Total.	Albuminoid. Dissolved.	Albuminoid. Suspended.	Nitrites.	Nitrates.	
Drainage canal at Kedzie avenue	April-June, 1900	215.8	188	28.7	9.87	8.05	5.01	2.9	1.31	.490	.22	.279	.0296	.289	1,332,000
Drainage canal at dam at Lockport	do	196	183	12.9	12.7	6.27	4.97	1.3	1.33	.347	.185	.161	.0185	.118	1,167,000
Desplaines River at Joliet (below town)		597.5	486.7	110.8	97.6	25.5	14.5	11	.128	.245	1.05	1.41	.011	.066	766,700
Desplaines River at Joliet (below Rock Island bridge or Jefferson street)		250	224	28	24.5	8	5.9	1.9	.387	.521	.255	.266	.0383	.287	1,054,000

So far as the chemical and bacterial conditions show, the condition of Illinois River at Kampsville, Averyville, and Grafton differs but slightly and in insufficient particulars from the water of the tributary streams. The witness then made the comparisons shown in Table 68. (5963–5967.)

TABLE 68.—*Comparison of samples from Illinois River and from its tributaries at stated points, 1899–1900.*

Sampling point.	Albuminoid ammonia (parts per million).		Oxygen consumed (parts per million), May to December, 1899.	Bacteria per cubic centimeter.	
	June to December, 1899.	January to June, 1900.		June to December, 1899.	January to June, 1900.
Kankakee River at Wilmington	0.352	0.327	.....	5,000	16,100
Fox River at Ottawa	.....	.42	8.3	6,500	20,600
Vermilion River at La Salle	.....	.285	.....	7,970	19,200
Sangamon River at Chandlerville	.....	.239	.....	5,080	24,200
Illinois River at Averyville	.447	.366	8.6	3,670	51,800
Illinois River at Kampsville	.....	.445	.....	4,810	33,700
Illinois River at Grafton	.400	.432	7.8	10,210	21,100

In considering the two cycles of self-purification which Illinois River undergoes in its course, the witness pointed out the similarity in the character of the water at Kampsville and Averyville, the former being about 124 miles from the great source of pollution at Peoria and the latter about 130 miles from the great source of pollution at Lockport. Throughout the period the presence of sewage from Chicago at Kampsville is not shown by any of the chemical determinations except that of chlorine, which is absolutely devoid of sanitary significance so far as purification of the stream is concerned, because it would be possible for a stream in the condition of Illinois River at Kampsville to be passed around the world several times in a closed conduit, consuming years or decades in the process, without materially altering the amount of chlorine in the water; and, in the judgment of the witness, on the supposition that the water were at the outset injurious to health, in the course of such a passage and in such a time it would become entirely free from any injurious qualities it might have originally possessed. (5968–5969.)

The witness then presented charts showing the amounts of chlorine, albuminoid ammonia, and free ammonia, and the number of bacteria per cubic centimeter at the various sampling points in Illinois River during the two periods, and also a chart showing a comparison between the number of bacteria in Mississippi and Illinois rivers above Grafton during the entire period. These charts are reproduced herewith. (Figs. 1 to 5.) The witness pointed out that they show the condition of the water throughout the river in 1900 to be superior to that in 1899 and that the chart showing the comparison of the number of bacteria in Mississippi and Illinois rivers is favorable to the Illinois. (5971–5980.)

The witness then took up the discussion of certain bacteriological determinations which he made along Illinois River between Morris and Ottawa, at Wesley, and at Grafton, the interval between the examinations in each series being one hour. The first of this series was made at Morris, October 7, 1899. The day was clear and sunny, the temperature of the air being 7° C. at 6 o'clock in the morning and

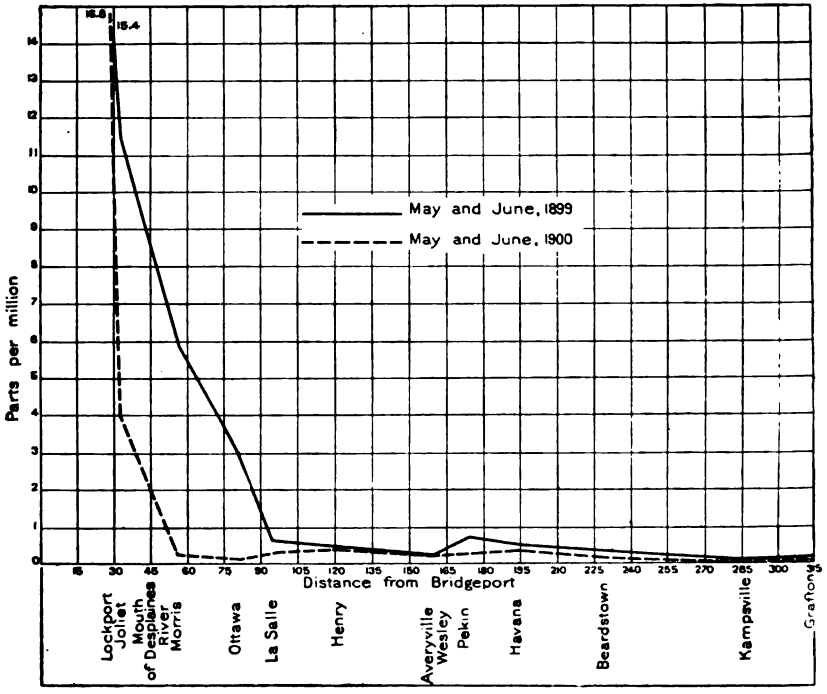


FIG. 1.—Diagram showing average chlorine in Desplaines and Illinois rivers, May and June, 1899 and 1900.

20.5° C. at midday. A slight breeze ruffled the surface of the water in the middle of the day, but was at no time strong. The river was low and the current exceedingly sluggish. Two cross sections of the river were selected and three samples were taken hourly at approximately equidistant intervals from one another and from the shores. The upper cross section was at a point just above the confluence of Mazon River with the Illinois, the lower about three-fourths of a mile below the mouth of Waupecan Creek. Little, if any, water was passing into the Illinois from these tributaries on this date. The stretch defined by these two cross sections is almost exactly 3 miles, and the rate of flow, as determined by floats and fluorescein, was found to be very close to one-half a mile per hour. The samples were plated immediately after collection. In Table 69 are given the results of the work. (5984–5986.)

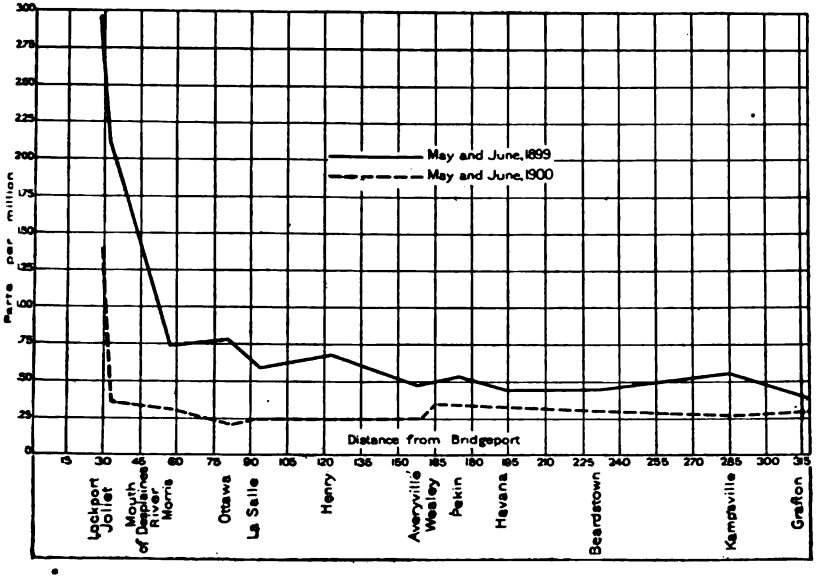


FIG. 2.—Diagram showing average albuminoid ammonia in Desplaines and Illinois rivers, May and June, 1899 and 1900.

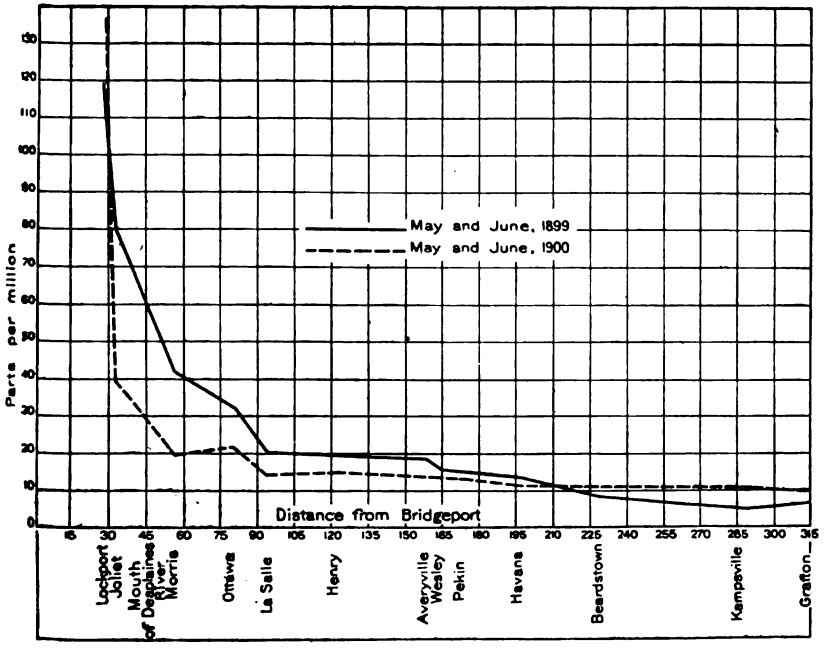


Fig. 3.—Diagram showing average free ammonia in Desplaines and Illinois rivers, May and June, 1899 and 1900.

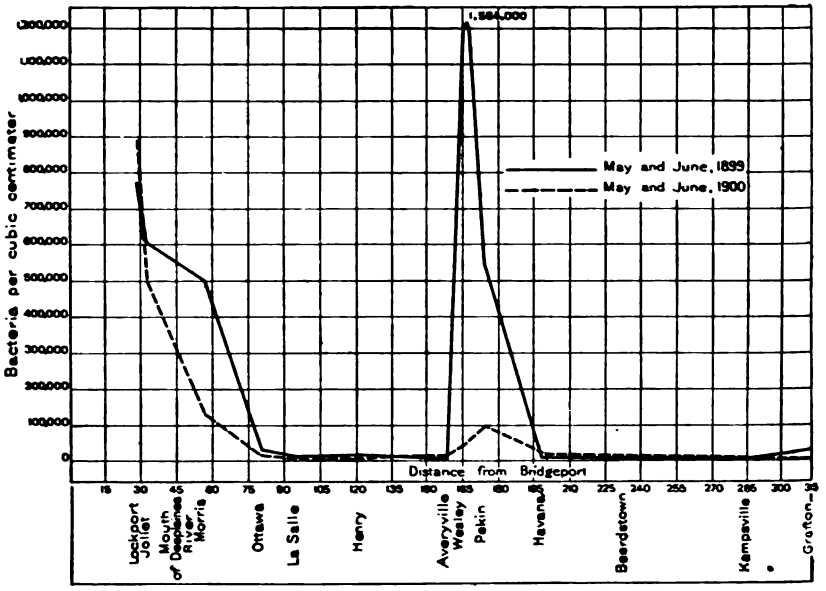


FIG. 4.—Diagram showing average bacteria in Desplaines and Illinois rivers, May and June, 1899 and 1900.

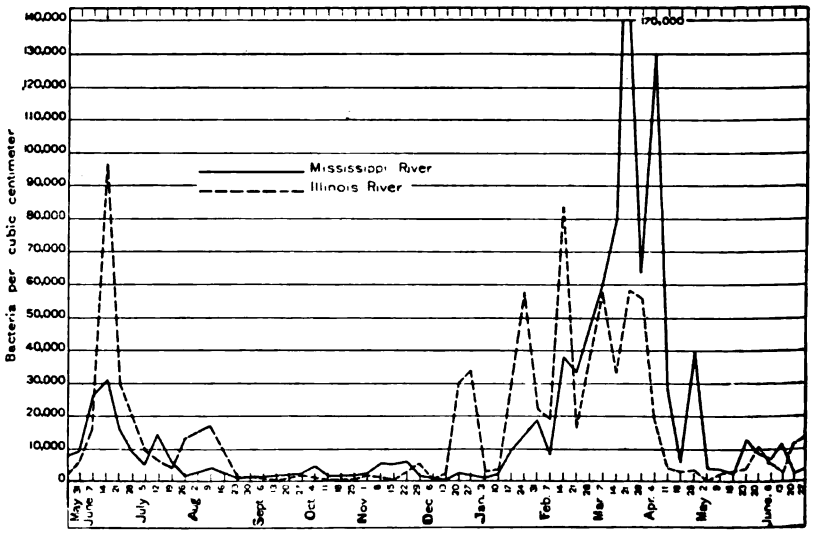


FIG. 5.—Diagram showing bacteria in Mississippi and Illinois rivers at Grafton, Ill., May 24, 1899, to June 29, 1900.

TABLE 69.—*Results of bacteriological determinations at Morris, October 7, 1899.*

UPPER STATION.

Time.	Sampling point.	Bacteria per cubic centimeter.	Turbidity (Hazen's scale).	Temperature of water (°C).	Chlorine (parts per million).
6.15 a. m.	Right bank	500,000	0.16	13	.....
	Center	378,000	.12	13	.....
	Left bank	42,000	.075	13	.....
7.15 a. m.	Right bank	368,000	.17	13	.....
	Center	344,000	.125	13	.....
	Left bank	35,000	.0775	13	.....
8.15 a. m.	Right bank	752,000	.16	13.5	91
	Center	364,000	.11	13	69
	Left bank	30,000	.0675	13	45
9.15 a. m.	Right bank	554,000	.16	14	.....
	Center	472,000	.11	14	.....
	Left bank	79,000	.075	14	.....

LOWER STATION.

12.15 p.m.	Right bank	480,000	0.13	16	.....
	Center	327,000	.15	16	.....
	Left bank	87,000	.05	16.5	.....
1.15 p.m.	Right bank	281,000	.1475	16	.....
	Center	102,000	.09	16	.....
	Left bank	19,000	.042	16	.....
2.15 p.m.	Right bank	400,000	.13	17	87
	Center	249,000	.09	16	72
	Left bank	22,000	.045	16	52
3.15 p.m.	Right bank	412,000	.136	17	82
	Center	416,000	.12	16	78
	Left bank	11,000	.0433	17	53

AVERAGES.

	Bacteria per cubic centimeter.			Number of hourly analyses.
	Right bank.	Center.	Left bank.	
Upper station	543,700	389,700	46,500	4
Lower station	393,250	273,500	34,750	4
Percentage of decrease	27.6	29.8	25.3	.....

In discussing the above table, the witness directed attention to what he believed to be a great bacterial purification between the two stations and pointed out that the determinations show a much better water along the left bank, which is due to the fact that at these two stations the water from Kankakee River predominates along that side of the stream and the mixing of this water and that from the Desplaines is incomplete.

The second series of observations was conducted November 9, 10, and 11, 1899, and was similar to that already outlined, except that it covered a more extended stretch of the river, namely, from Morris to Ottawa, the two being about 24 miles apart. At the time these observations were made the rate of flow averaged about one-half mile per hour. At Seneca, a point about midway between these two stations, a third cross section was selected. During the observations the sun was wholly obscured by clouds, but no rain fell. (5986–5988.)

TABLE 70.—*Results of bacteriological determinations at Morris, Seneca, and Ottawa, November 9–11, 1899.*

MORRIS (NOVEMBER 9).

Time.	Sampling point.	Bacteria per cubic centimeter.	Turbidity (Hazen's scale).	Temperature of water (°C.).	Chlorine (parts per million).
7.15 a. m	Right bank	433,000	0.153	7	.....
	Center	337,000	.13	7	.....
	Left bank	30,000	.046	7	.....
11.30 a. m	Right bank	177,000	.17	7.25	67.5
	Center	145,000	.18	7.25	47.5
	Left bank	17,000	.02	7.25	8
2 p. m	Right bank	174,000	.15	3	.....
	Center	131,000	.135	3	.....
	Left bank	49,000	.05	3	.....

SENECA (NOVEMBER 10).

9 a. m	Right bank	134,000	Less than 0.09.	9.5	51
	Center	47,000	More than 0.07.	9.5	44
	Left bank	23,000	.....	9.5	35
1.30 p. m	Right bank	67,000	.....	11	.....
	Center	52,000	.....	11	.....
	Left bank	52,000	.....	11	.....

OTTAWA (NOVEMBER 11).

10 a. m	Right bank	11,000	Less than 0.04.	9.5	49
	Center	10,500		9.5	46
	Left bank	3,900		9.5	43
1 p. m	Right bank	12,000	.....	9.5	.....
	Center	11,000	.....	9.5	.....
	Left bank	18,000	.....	9.5	.....

AVERAGES.

	Bacteria per cubic centimeter.			Number of analyses.
	Right bank.	Center.	Left bank.	
Morris	261,000	204,000	29,000	3
Seneca	100,000	49,000	35,000	2
Ottawa	11,500	10,700	13,500	2

In discussing the above results the witness stated that, according to the figures, Illinois River, during this flow of 24 miles became nearly free from the great mass of sewage bacteria with which it was originally laden—in fact, the bacterial content of the Illinois at Ottawa on the above date was not greatly in excess of that of the local tributary streams.

He then reviewed the results of the chemical determinations made during the regular examinations at the Chicago laboratory during the period between October 23 and November 20, 1899, the points of collection being Morris and Ottawa. These results, according to the witness, show that a considerable degree of nitrification takes place in the river between these two stations.

The third series of observations was made at the same points as the second series, May 24, 25, and 26. The sun was partially obscured May 25, but shone brightly on the remaining two days; no rain occurred during the period. The results are presented in Table 71. (5988–5990.)

TABLE 71.—*Results of bacteriological determinations at Morris, Seneca, and Ottawa, May 24–26, 1900.*

MORRIS (MAY 24).

Time.	Sampling point.	Bacteria per cubic centimeter.	Temperature of water (°C.).	Chlorine (parts per million.)
7.30 a. m	Right bank	45,000	15.5	20
	Center	74,000	17.5	13
	Left bank	42,000	18	8
9.30 a. m	Right bank	60,000	15.5	.....
	Center	34,000	17	.....
	Left bank	39,000	18	.....
11.30 a. m	Right bank	98,000	15.75	.....
	Center	62,000	17	.....
	Left bank	30,000	18	.....
2 p. m.[a]	Right bank	70,000	16	21
	Center	63,000	17	14
	Left bank	48,000	18	6

SENECA (MAY 25).

7.30 a. m	Right bank	13,800	16.5	19.5
	Center	11,700	.....	16
	Left bank	4,100	.....	13
9.30 a. m	Right bank	12,700	17	.....
	Center	14,000	.....	.....
	Left bank	16,000	.....	.....
11.30 a. m	Right bank	4,500	17.5	.....
	Center	4,100	.....	.....
	Left bank	3,000	.....	.....
1.30 p. m	Right bank	5,500	18.5	16
	Center	6,700	18.8	15
	Left bank	13,100	19.7	12

OTTAWA (MAY 26).

9.30 a. m	Right bank	7,400	18.5	15
	Center	10,000	18.5	14
	Left bank	8,300	18.5	13
11 a. m	Right bank	8,100	19	17
	Center	6,800	19.2	15
	Left bank	6,400	19.2	14
2.00 p. m	Right bank	9,000	19.5	17
	Center	6,300	19.5	16
	Left bank	4,200	20	14

[a] Samples were taken at this time and submitted to chemical examination, with the following results stated in parts per million:

	Right bank.	Center.	Left bank.
Residue on evaporation:			
Total	232	246	308
Dissolved	230	244	285
Suspended	2	2	23
Chlorine	21	14	6
Oxygen consumed:			
Total	6.6	7.2	8.8
By dissolved matter	6.1	6.0	4.7
By suspended matter	.5	1.2	4.1
Free ammonia	2.28	1.08	.24
Albuminoid ammonia:			
Total	.256	.296	.240
Dissolved	.224	.224	.168
Suspended	.032	.072	.072
Nitrites	.072	.050	.040
Nitrates	.4	1.1	.95

TABLE 71.—*Results of bacteriological determinations at Morris, Seneca, and Ottawa, May 24-26, 1900*—Continued.

AVERAGES.

	Bacteria per cubic centimeter.			Number of analyses.
	Right bank.	Center.	Left bank.	
Morris	68,200	58,200	39,800	4
Seneca	9,100	9,100	10,300	4
Ottawa	8,200	7,700	6,300	3

The witness stated that the above results show a more complete mixing of the Kankakee and Desplaines waters, also a smaller number of bacteria, than in the determinations made in 1899. It should be remembered in this connection that this last series of examinations was made after the opening of the Chicago drainage canal. The witness then made the following statement:

I see no escape from the conclusion that in this flow of approximately 24 miles the Illinois River, which at Morris contained a large number of bacteria, in all probability derived more or less directly from the sewers of Chicago, freed itself from these bacteria to a remarkable and impressive degree in a short distance and in a relatively short space of time. (5991.)

These observations on the bacterial content of the river at Morris and Ottawa indicated that a very large proportion of the bacteria entering at Lockport do not survive long enough to reach Ottawa, which fact renders it improbable that disease germs can pass down the stream as far as this point. Since the sewage bacteria disappeared so largely, it is fair to assume that the various nonspore-forming pathogenic bacteria must die out at least in the same proportion. In giving this opinion, the witness stated that he was taking into consideration all the knowledge that he possessed of the life of pathogenic germs and their relation to sewage bacteria. (5993.)

The witness then described some cross-section experiments which he had made at Wesley, June 13, 1900, the results being as follows:

TABLE 72.—*Results of bacteriological determinations at Wesley, June 13, 1900.*

	Free ammonia (parts per million).	Albuminoid ammonia (parts per million).	Bacteria per cubic centimeter.
Right bank	0.504	0.864	4,340,000
Center	.144	.248	40,000
Left bank	.168	.240	2,400

According to the witness, the large amount of pollution entering the river from Peoria on the right bank is clearly shown in this series of samples, the quantity of free and albuminoid ammonia and the number of bacteria being very much greater on the right than on

the left bank of the stream. He then stated that on a number of occasions both in 1899 and 1900 similar cross-section samples were taken from Illinois River at Grafton, but only the determination of bacteria per cubic centimeter was made. In a general way the results showed that the samples taken near the right and left banks of the stream were not materially different from those taken at the center, the mixing of the water being complete at this point. Slight variations were sometimes noticed, but they were not confined to any particular portion of the stream. (5992–5993.)

The witness then took up the discussion of *Bacillus coli communis*, and in response to leading questions gave the following testimony:

Bacillus coli communis in large numbers inhabits a portion of the alimentary tract known as the colon. It is sluggishly motile and does not form spores. It is found in the intestinal discharges of man and of other higher animals and also in soils and waters contaminated with animal excreta. Sometimes it is found in the dust of the streets, its occurrence there being probably due to infection from horse droppings. The colon bacillus is in many ways similar to the typhoid bacillus. It resembles the latter in shape, size, motility, and lack of spore formation so closely that bacteriologists have some difficulty in distinguishing between the two organisms. The growth of both upon beef broth and gelatine agar is apparently identical. In fact, both bacteria belong to a group in which there are both pathogenic and nonpathogenic organisms. Although the typhoid and the colon bacillus are thus intimately related, there are, nevertheless, certain constant characteristics which enable an experienced observer to distinguish between them. Some of the main points of difference are that the colon bacillus is able to ferment dextrose with gas production, while the typhoid bacillus does not under any circumstances produce gas. When grown in milk the colon bacillus produces acid from the milk sugar and curdles the milk, while the typhoid bacillus is not able to do this.

The colon bacillus is much more hardy than the typhoid bacillus. Comparative tests of viability have shown the following:

1. Ninety-nine and nine-tenths per cent of *Bacillus coli* and 100 per cent of *B. typhosus* were removed by an intermittent water filter, and 99.8 per cent of the former and 99.9 per cent of the latter were removed by a continuous filter.

2. After the infected water had been applied to these filters, *B. coli* was found to continue in the effluent from the intermittent filter for twenty-four to thirty-six hours, while the *B. typhosus* continued only for two or three hours.

3. In a water subjected to a temperature of 33° F. about 90 to 95 per cent of both species were destroyed in twenty-four hours. A

few organisms of each species may, however, live for a con
number of days.

4. About 55 per cent of *B. coli* and 75 per cent of *B. typh*
destroyed by about fifteen minutes freezing. After one
per cent of the former and 98 per cent of the latter were l
the end of twenty-four hours over 99 per cent of all the
had disappeared.

5. Both species resist temperatures up to 45° C. for fiv
between 45° and 50° C. all but a few individuals of each
destroyed. These few individuals, however, resisted temp
to 85° C, at which all organisms of both species were dest

The witness further stated that, according to some e
made by him on the typhoid bacillus when introduced in
Lake Michigan water, the organism does not multiply, but
certain conditions maintain its vitality for upward of r
days. *Bacillus coli communis*, on the other hand, multipl
this water and may remain alive for upward of two h
sixty-three days. (5995–5997.)

Summing up the above, the witness stated that it is clea
the two species resemble each other in many important
colon bacillus has been proved to possess a greater resi
the typhoid bacillus.

Concerning the significance of the *Bacillus coli communis*
tion in sanitary water analyses, the witness stated that thi
one of the prevailing bacterial forms in fresh sewage, and f
son its presence and relative abundance in water are regar
stituting one of the most significant indications of recent
lution. He then cited experiments made by Dr. William
of Buffalo, and Dr. William G. Savage, of University Colle
Wales; also a report of a committee of the laboratory se
American Public Health Association, all of which showed
cance of the presence of *B. coli communis* as indicating sewag
He then cited the work carried on in connection with th
ment of a water-purification system at New Orleans in 190
a quotation from page 47 of this report as follows:

> In waters which contain unpurified sewage the test for this intestinal
> the utmost importance. In the Mississippi River at New Orleans, how
> evidently so much self-purification effected by natural agencies, such as
> mentation, etc., that this normal intestinal bacillus was one of the least
> isolated. In about 100 tests with a volume of water varying from 1 to 30
> ence was demonstrated only three times, although the larger samples of w
> centrated in a centrifuge before being seeded into the media conveyed i
> tubes.

Further quotation was made from the report, contrastin
evidence with that of the water from the Merrimac at La
Hudson below the Mohawk, the Ohio at Cincinnati, the Sch

the Potomac, and a further observation was made that the conditions in Mississippi River above New Orleans are so favorable for self-purification during the last few hundred miles of its flow that the normal bacteria of surface water effectually crowd out those derived from populated and cultivated areas. This instance was regarded by the witness as especially significant of the ability of streams to purify themselves, especially in view of the fact that countless millions of colon bacilli are contributed by the cities in the Ohio, Illinois, upper Mississippi, and Missouri basins. (6000–6004.)

The witness then outlined the methods used for isolating the colon bacillus (see pp. 6005–6008 of the record) and gave an account of experiments made on the water of the Illinois and Mississippi systems at various points. The results of the experiments and the points of collection are shown in Table 73. (6009–6035.)

TABLE 73.—*Results of presumptive tests for Bacillus coli communis on samples of water from designated points before and after the opening of the Chicago drainage canal.*

Sampling point.	Date.	0.00001 c. c.		0.0001 c. c.		0.001 c. c.		0.01 c. c.		0.1 c. c.		1 c. c.		5 c. c.	
		Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.
Illinois and Michigan Canal at Lockport	1899	8	2	9	9	1	1	1	1	1	1	....	....	....	....
	1900	20	5	24	19	10	7	3	3	1	1	....	....	....	....
Drainage canal at Kedzie avenue	1900	3	0	7	1	8	3	7	4	3	3	....	....	....	....
Drainage canal at Lockport	1900	2	0	10	1	11	3	10	6	4	4	....	....	....	....
Desplaines River at Lockport	1899	....	....	....	....	....	....	1	0	8	1	5	2	....	....
Kankakee River at Wilmington	1899	....	....	....	....	....	....	....	....	6	3	5	4	....	....
Illinois River at Morris	1899	....	....	3	1	5	5	5	5	....	....	....	....	....	....
	1900	....	....	....	....	15	6	25	15	23	20	9	8	....	....
Fox River at Ottawa	1899	....	....	....	....	....	....	....	....	9	0	8	1	....	....
	1900	....	....	....	....	....	....	....	....	13	2	15	5	13	10
Illinois River at Ottawa	1899	....	....	....	....	....	....	8	4	12	7	10	6	....	....
	1900	....	....	....	....	....	....	14	2	22	12	22	14	6	4
Vermilion River at La Salle	1899	....	....	....	....	....	....	....	....	6	1	9	3	....	....
Illinois River at La Salle	1899	....	....	....	....	....	....	....	....	7	2	8	3	....	....
Illinois River at Henry	1899	....	....	....	....	....	....	1	0	6	2	8	3	....	....
	1900	....	....	....	....	....	....	....	....	2	2	3	3	....	....
Illinois River at Averyville	1899	....	....	....	....	....	....	....	....	5	1	9	2	....	....
	1900	....	....	....	....	....	....	1	0	23	3	22	11	....	....
Illinois River at Wesley	1899	....	....	1	0	....	....	3	0	7	3	4	2	....	....
	1900	....	....	6	1	....	....	19	3	19	10	14	11	....	....
Illinois River at Havana	1899	....	....	....	....	....	....	....	....	4	2	8	6	....	....
Sangamon River at Chandlerville	1899	....	....	....	....	....	....	....	....	3	2	5	3	....	....
	1900	....	....	....	....	....	....	13	4	22	12	22	18	....	....
Illinois River at Grafton	1899	....	....	....	....	....	....	3	1	10	4	13	7	....	....
	1900	....	....	....	....	....	....	1	0	25	10	25	19	4	2
Mississippi River at Grafton	1899	....	....	....	....	....	....	2	0	10	1	11	6	....	....
	1900	....	....	....	....	....	....	....	....	24	9	24	17	4	3
Mississippi River at Alton:															
East bank	1899	....	....	....	....	....	....	....	....	7	0	7	1	....	....
East of center	1899	....	....	....	....	....	....	....	....	7	1	7	1	....	....
Center	1899	....	....	....	....	....	....	....	....	7	1	7	1	....	....
West of center	1899	....	....	....	....	....	....	....	....	7	2	7	2	....	....
West bank	1899	....	....	....	....	....	....	....	....	5	0	5	2	....	....
Missouri River at Fort Bellefontaine	1899	....	....	....	....	....	....	....	....	6	0	6	1	....	....
	1900	....	....	....	....	....	....	6	3	26	13	25	20	....	....
Mississippi River at intake tower	1899	....	....	....	....	....	....	....	....	5	2	5	3	....	....
	1900	....	....	....	....	....	....	2	2	17	11	17	14	....	....
St. Louis tap water	1899	....	....	....	....	....	....	....	....	5	0	5	3	....	....
	1900	....	....	....	....	....	....	....	....	24	5	25	12	....	....
Total for Illinois River		....	....	....	....	....	....	....	....	62	17	69	39	....	....
Tributaries of Illinois River		....	....	....	....	....	....	....	....	66	21	69	36	....	....
Mississippi and Missouri rivers		....	....	....	....	....	....	....	....	66	23	66	44	....	....

Referring to the above results, the witness made the following statements:

On comparing the number of days on which *Bacillus coli* was found in 1 c. c. of water taken from Illinois River at Averyville and Grafton, from the Mississippi at Grafton, from the Desplaines, from the Kankakee, from the Fox, from the Vermilion, from the Sangamon, and from the Missouri, it appears that, so far as the colon-bacillus content enables one to pass an opinion on the sanitary quality of these waters, Sangamon River at Chandlerville is one of the more highly polluted streams.

The Illinois at Grafton, the Mississippi at Grafton, and the Missouri at Fort Bellefontaine appeared to be on substantially the same footing with one another in respect to their colon-bacillus content, while the Fox contained a smaller proportion of colon bacilli than any other of the streams under consideration.

The Illinois at Averyville compares in respect to its colon-bacillus content very favorably with the Illinois and Mississippi above Grafton and the Missouri above its mouth and is perceptibly less highly contaminated than the Sangamon at Chandlerville.

To sum up these facts, it is seen that samples of water taken on sixty-nine different days from Illinois River at Averyville and at Grafton contained *Bacillus coli communis* on thirty-nine days, while samples taken from the various tributaries of the Illinois on sixty-nine days contained the colon bacillus on thirty-six days. Samples taken from the Missouri on sixty-six days contained the colon bacillus on forty-four days.

It appears, therefore, from these tables that if the opinion expressed by the witness regarding the sanitary significance of the colon bacillus in water is correct, the water of Illinois River at Averyville and Grafton was not materially different from what it would have been if the tributaries of the Illinois, exclusive of Desplaines River and its sewage content, had alone fed the basins of this stream. The colon-bacillus content of such a stream at Averyville and at Grafton would have been substantially what it is at present. (6038–6039.)

In connection with the discussion of these results, the witness made the interesting statements reproduced below in response to specific questions:

Q. Professor, I desire to call your attention to the testimony of Doctor Ravold. On page 150 of his testimony given in this case Doctor Ravold testified that the colon bacillus was found in 72 per cent of the samples taken from the Bear Trap dam at Lockport in the month of March, 1900, and at page 320 of his testimony he testified that the *Bacillus coli communis* was found in 71 per cent of the samples collected from the St. Louis settling basins during the period from May 1 to October 31, 1900. Would you infer from those statements that colon bacillus was present in the water of these settling basins in St. Louis in anything like the same proportion that it was in the water of the drainage canal at Lockport?

A. I certainly should not.

Q. Give your reasons.

A. It is very important in making the test for the colon bacillus, especially when a polluted water is being dealt with, to use dilutions of the water high enough to prevent the overgrowth of the colon bacillus by other sewage forms. I have frequently in my own experience found that by the use of so large a quantity of water as 1 c. c. * * * apparently negative results are obtained, while by examination of a smaller quantity of the same water positive results invariably appear. The explanation for this phenomenon, which may prove very misleading, is that when a large quantity of sewage-polluted water is introduced into fermentation tubes other forms of bacteria, such as some of the anaerobic bacteria, are present. These overgrow the colon forms, leading to an apparently negative result, and thus completely obscuring the true interpretation. I have frequently encountered this difficulty in dealing with highly polluted waters in using quantities as large as 1 c. c. It is my opinion that if the colon determination be carried out properly, with due regard to the difficulties here mentioned, the colon bacillus would be found to be present in every cubic centimeter of the water in the drainage canal. Indeed, my examinations have shown no fewer than several hundred colon bacteria per cubic centimeter in the water of the drainage canal, and generally several thousands, while in the water of the Mississippi River which is pumped into the settling basins at St. Louis and in the tap water drawn from the tap in St. Louis the number of colon bacteria never approximate anything like these figures.

For these reasons I am compelled to assume that the statements to which you refer are based on defective analytical methods and do not indicate that the actual number of colon bacilli in the water of the drainage canal and in the St. Louis settling basins are at all comparable. (6012–6014.)

The witness then took up the discussion of the work performed from October to December, 1901, and stated that three extra laboratories were equipped at the direction of the defendants, one at Peoria, on Illinois River; one at Grafton, at the mouth of the river, and one at St. Louis. The work carried on at these three laboratories consisted chiefly in plating daily samples of water for bacteriological examination and in making colon determinations. Data were also procured concerning the temperature of the water and air at times of collection, and all the laboratory men were instructed to select from the colonies of bacteria appearing on the plates all the different kinds that could be distinguished by the peculiarities of their growth. Those colonies thus picked from the plates were transferred to agar tubes and shipped to the witness at the bacteriological laboratory of the University of Chicago, where they were studied in detail. (6041–6042.)

The sampling points were as follows: For the Peoria laboratory, at Averyville, above Peoria, and at Pekin, below Peoria, the precise points of collection being approximately those used during the investigations of 1899 and 1900; for the laboratory at Grafton, from Illinois River above its confluence with the Mississippi and from the Mississippi above the mouth of the Illinois; for the laboratory at St. Louis, five daily samples, four along the cross section at Chain

of Rocks and the fifth from Missouri River at Fort Bellefonta
The bacteriological work consisted of, first, the determination of
number of bacteria in the samples, as shown by the ordinary co
counts; second, the number of germs of the colon group, as sh
by the dextrose fermentation tube test, and, third, the study
bacterial flora. The first two determinations were carried on in
respective branch laboratories and the third was performed at
laboratory of the University of Chicago. (6042–6043.)

The methods used for the chemical estimation were those re
mended by the committee on standard methods of the American
lic Health Association. Several different decimal dilutions of
water were usually employed, and the dilution that was selecte
record was the one showing from about 25 to 125 colonies per p
(6043–6044.)

The results of the various examinations are reported in deta
pages 6046–6080 of the record. A summary is given in Table 7

TABLE 74.—*Average results of bacterial determinations on water from Illinois, Miss and Missouri rivers, October to December, 1901.*

Sampling point.	Number of determinations.	A
Illinois River at Averyville (above Peoria)	69	
Illinois River at Pekin (below Peoria)	50	
Illinois River at Grafton	73	
Mississippi River at Grafton	73	
Mississippi River at Chain of Rocks:		
Illinois shore	54	
Midstream	53	
Intake tower	52	
Missouri shore	53	
Missouri River at Fort Bellefontaine	51	

Concerning the above results, the witness stated that the numl
bacteria found at Averyville and at Grafton were not dissimilar.
averages were higher than the average for this period in Missi
River, owing to the fact that the usual winter increase which o
in river waters took place that year earlier in Illinois River th
did in Mississippi River. Up to the middle of December, 1901
two waters were very similar as regards their bacterial con
Throughout the period studied the average number of bacteri
shown by the colony count, for Missouri River at Fort Bellefon
was several times as great as in the water from either Illinois Riv
its mouth or Mississippi River above Grafton. The number of
teria in Illinois River water at Pekin was greatly in excess of
found at any of the other collecting stations—a fact which, i
opinion of the witness, naturally follows the entrance of sewag
refuse into the river at Peoria, just above this point. (6081.)

The witness then presented a table showing the comparative number of bacteria in samples from Mississippi River taken along the cross section at Chain of Rocks and from Missouri River at Fort Bellefontaine. This table appears on pages 6082–6083 of the record. The witness said that the figures show that during the period covered by the investigation, the number of bacteria in the water of Mississippi River along the cross section was much lower on the Illinois shore than on the Missouri shore, and further that the water at the intake tower partook of the character of the waters of Missouri River and of Mississippi River on the Missouri shore. In other words, during these three months of 1901 little, if any, water from Illinois River entered the intake tower of the St. Louis waterworks, and it was also evident from the bacterial count that if any of the water from the Illinois shore did pass into the intake it must have improved the condition of the water, so far as reducing the number of bacteria per cubic centimeter was concerned. (6084.)

The witness then introduced into evidence three series of photographs of bacterial plates, showing the number of bacteria in samples taken from Mississippi River at four points in the Chain of Rocks section—Illinois shore, mid-channel, intake tower, and Missouri shore—and from Missouri River at Fort Bellefontaine. The first series represented plate samples taken October 28; the second, November 20, and the third, December 13. The plates were all agar platings, and the photographs represented the number of colonies developing in 0.1 c. c. of the water. The number of colonies visible on each plate from each sampling point agreed with the statements made by the witness concerning the relative appearance of bacteria and the proportions shown in Table 74. (6084–6089.)

The witness then discussed the tests for *Bacillus coli communis* made during this period, stating that he considered that the relative abundance of this organism afforded the most satisfactory test of the sanitary quality of the water, and citing various authorities in substantiation of his opinion.

The detailed report of these tests appears on pages 6097–6116 of the record. A summary of the results appears in Tables 75 and 76. (6118–6120.)

TABLE 75.—*Presence of bacteria of the colon group in samples from designated points, October to December, 1901.*

Sampling point.	0.0001 c. c.		0.001 c. c.		0.01 c. c.		0.1 c. c.		1 c. c.		2 c. c.		5 c. c.	
	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.	Number of days water examined.	Number of days B. coli found.
Illinois River at Averyville			3	0	49	3	60	38	41	34				
Illinois River at Pekin	17	4	44	14	44	40	17	17						
Illinois River at Grafton			52	4	64	6	64	12	53	19	13	5	16	[illegible]
Mississippi River at Grafton			52	0	64	6	62	25	54	25	12	4	16	11
Mississippi River at Chain of Rocks:														
Illinois shore			25	0	41	3	41	8	42	25			7	5
Midstream			27	0	41	4	41	16	42	35			7	6
Intake tower			27	0	43	11	42	30	43	36	6	6	5	5
Missouri shore			27	1	41	8	41	24	41	36			4	4
Missouri River at Fort Bellefontaine			32	1	44	13	44	31	43	34			8	7

TABLE 76.—*Number and percentage of results showing presence of bacteria of the colon group in samples from designated points, October to December, 1901.*

Sampling point.	0.0001 c. c.			0.001 c. c.			0.01 c. c.			0.1 c. c.		
	Number of determinations made.	Number of positive results.	Percentage of positive results.	Number of determinations made.	Number of positive results.	Percentage of positive results.	Number of determinations made.	Number of positive results.	Percentage of positive results.	Number of determinations made.	Number of positive results.	Percentage of positive results.
Illinois River at Averyville	25	7	28	3	0	0	72	4	6	114	49	43
Illinois River at Pekin				75	16	21	77	60	78	17	17	100
Illinois River at Grafton				72	5	7	117	6	5	125	16	13
Mississippi River at Grafton				69	0	0	115	6	5	125	29	24
Mississippi River at Chain of Rocks:												
Illinois shore				25	0	0	66	3	5	80	8	10
Midstream				27	0	0	68	4	6	82	18	22
Intake tower				27	0	0	71	14	20	84	48	[illegible]
Missouri shore				27	1	4	68	9	13	81	33	[illegible]
Missouri River at Fort Bellefontaine				34	1	3	84	16	19	95	48	50

Sampling point.	1 c. c.			2 c. c.			5 c. c.		
	Number of determinations made.	Number of positive results.	Percentage of positive results.	Number of determinations made.	Number of positive results.	Percentage of positive results.	Number of determinations made.	Number of positive results.	Percentage of positive results.
Illinois River at Averyville	34	20	59						
Illinois River at Grafton	71	21	30	15	5	33	17	8	47
Mississippi River at Grafton	74	22	30	12	4	33	16	11	69
Mississippi River at Chain of Rocks:									
Illinois shore	42	25	60				7	5	71
Midstream	43	22	51	6	6	100	7	6	86
Intake tower	43	22	44				5	5	100
Missouri shore	42	23	55				4	4	100
Missouri River at Fort Bellefontaine	44	25	57				8	7	88

In discussing the above results the witness stated that the fact that the colon bacillus was found to be present in but 43 per cent of the 0.1 c. c. samples from Illinois River at Averyville, while it was present in 100 per cent of the 0.1 c. c. samples from the same river at Pekin and in only 13 per cent of the 0.1 c. c. samples from Illinois River at Grafton, shows not only the extreme delicacy of the test for sewage pollution, but also a very considerable improvement in the sanitary quality of water between Pekin and Grafton. A comparison of the water of Mississippi River above Grafton with that of Illinois River above the same point indicates that the colon bacillus was present in 5 per cent of the 0.01 c. c. samples of water from these two places. Of the samples from the same points containing 0.1 c. c. of water, 24 per cent of those from Mississippi River and only 13 per cent of those from Illinois River yielded positive results, and a similar difference was noted in the 1 c. c. samples, all of which showed, in the opinion of the witness, that the water of Mississippi River above Grafton during the period of examination was, if anything, less wholesome than that of Illinois River above Grafton. With reference to the results found in waters from Mississippi River at Chain of Rocks and Missouri River at Fort Bellefontaine, the witness stated that the water from Missouri River during this period was distinctly more dangerous and unwholesome than that of either the Illinois or the Mississippi at Grafton. (6121–6123.)

The witness then introduced photographs of fermentation tubes, showing the results of inoculations with quantities of water varying from 0.001 to 1 c. c., taken from the designated sampling stations. The illustrations show that the colon bacillus was not so abundant in the water of Mississippi River near the Illinois shore as it was at the intake tower of the St. Louis waterworks.

From all the foregoing tables and illustrations the witness concluded that the effect of any mixture of Illinois River water with Missouri River water at the intake tower would tend to diminish the colon content of the water at such point, thereby rendering it less dangerous for human use. (6132.)

The attention of the witness was then called to that part of the testimony of Allen Hazen in which he stated that the mixing of water from Illinois and Mississippi rivers by the time it reaches the mouth of the Missouri River is more complete at low water than at high water, to which the witness replied that the total number of bacteria in the water at the intake tower and near the Missouri shore at Chain of Rocks, as well as the number of colon bacteria in the water at these two points, shows conclusively that during the period of low water the water collected at these two stations was almost wholly, if not altogether, Missouri River water and was mixed little, if any, with that

of the Illinois. If it be true, therefore, that the mixing is more complete at low water than at high water, it would certainly follow that the amount of Illinois River water present in the Mississippi at these two points at high-water stages must be exceedingly small. (6132-6133.)

The witness then discussed his work in the identification of bacteria of various species in the samples collected during the investigation of 1901. The organisms studied were isolated from four different kinds of culture media—(1) from forty-eight-hour gelatine plates incubated at 20° C.; (2) from forty-eight-hour dextrose-broth fermentation tubes incubated at 37°; (3) from litmus lactose agar plates at 35° after passing through carbol broth at 37°; (4) from neutral red broth at 37°. In this way 543 cultures were isolated and classified. The results are contained in Table 77. (6134.)

TABLE 77.—*Species of bacteria isolated by E. O. Jordan, 1901.*

Species.	Illinois River.			Mississippi River.						
					Chain of Rocks.					
	Averyville.	Pekin.	Grafton.	Grafton.	Missouri shore.	St. Louis intake.	Channel.	Illinois shore.	Missouri River at Port Bellefontaine.	Total.
Bacillus coli communis	3	22	1	7	4	2	1	3	3	46
B. lactis aerogenes	7	8	1	5	.....	3	1	1	1	27
B. coli communis and B. lactis aerogenes	6	12	1	.....	4	1	.....	3	2	29
Proteus	13	4	5	7	2	3	2	2	2	40
B. cloacæ	5	1	5	1	2	4	1	2	.....	21
B. enteritidis	3	2	.....	.....	1	.....	.....	.....	.....	6
B. fluorescens liquefaciens	8	3	7	9	1	.....	2	3	.....	33
B. fluorescens nonliquefaciens	7	1	2	2	4	1	5	1	2	25
B. subtilis	6	2	12	4	4	6	4	2	6	46
B. gelat.-liquef., milk acid	19	11	10	15	4	6	.....	1	8	74
B. gelat.-liquef., milk alkaline	7	10	7	2	2	1	.....	1	.....	30
B. nongelat.-liquef., milk acid	6	8	2	.....	3	2	6	4	1	32
B. nongelat.-liquef., milk alkaline	17	1	1	.....	2	1	4	2	1	29
B. nongelat.-liquef., milk amphoteric	17	6	2	1	.....	1	.....	1	2	30
Chromogenic bacteria [a]	7	3	1	1	2	1	1	1	.....	19
Chromogenic staphylococci	2	2	5	1	1	1	1	1	.....	14
Nonchromogenic staphylococci	4	17	3	2	2	.....	4	1	2	35
Sarcinæ	2	.....	.....	1	.....	.....	.....	.....	.....	3
Streptococci	.....	2	.....	.....	2	.....	.....	.....	.....	4
	139	115	65	58	40	33	32	29	30	543

[a] Two cultures of the red chromogenic group are without data as to place or mode of isolation.

Referring to the above results, the witness stated that the detailed study shows that the forms regarded by bacteriologists as characteristic of sewage pollution are found more abundantly in the water of Illinois River at Pekin than elsewhere. The streptococcus forms, which are believed to be especially characteristic of recent sewage pollution, were found in only four cases, namely, two in Illinois River at Pekin and two in Mississippi River at Chain of Rocks, near the Missouri shore. (6135.)

In response to a question concerning the necessity for examination of samples collected hourly or even daily, the witness cited several

standard investigations, such as those carried on by George W. Fuller at New Orleans, Louisville, and Cincinnati, and by Allen Hazen at Pittsburg, together with certain others in European countries. He stated that in his opinion the usual practice is based on the belief that an adequate opinion as to the character of the water can be formed by examinations made at intervals of one week, provided the total period of investigation extends over a sufficient length of time. In the present investigation the weekly, daily, and hourly determinations made by the witness, together with those made concurrently by Professors Palmer, Long, Zeit, Gehrmann, and Burrill, were unquestionably sufficient to permit a satisfactory conclusion to be drawn as to the character of the water, and they constituted the most extensive study of river water, in connection with the subject of self-purification of streams, ever made anywhere in the world. (6135–6137.)

Taking into consideration all the analytical data obtained throughout the seventeen months covered by the investigations, the witness concluded that one of the most remarkable facts brought out is the entire concurrence of the results derived from the chemical and the various bacteriological determinations. The amount and rate of nitrification in the water of Illinois River at various points along its course are in line with what the experience of water analysts has shown to accompany real purification. On the bacteriological side the evidence is wholly confirmatory, as under certain conditions Illinois River becomes nearly free from the great mass of sewage bacteria with which it is laden at Lockport in so short a distance as 24 miles, as shown by the examinations made at Morris and Ottawa. (6138–6140.)

Concerning the occurrence of *Bacillus prodigiosus* in the rivers of the country, the witness stated that on November 6, 1899, he isolated from the water of Illinois River collected at Morris an organism which resembled in all specific characteristics the standard *B. prodigiosus*, and verified his diagnosis by comparing its culture characteristics with those of two other strains obtained from the University of Michigan and Yale University. In addition to these, he isolated from the water of Mississippi River near the Missouri shore at Chain of Rocks on November 16, 1901, an organism that in many respects was typical of *B. prodigiosus* and might have been mistaken for it, but was markedly different in other characteristics, inasmuch as it did not produce gas in dextrose broth nor liquefy blood serum nor curdle milk—three very important respects in which it differed from the true *B. prodigiosus* type. Other germs were isolated on other occasions from Illinois and Mississippi rivers, which also bore certain resemblances to *B. prodigiosus*, but which on investigation were found not to be the true form. (6143–6144.)

In response to the hypothetical questions hereinbefore
concerning the experiment of Doctor Ravold in depositing 10
of *B. prodigiosus* culture in the Chicago Drainage Canal, the
tated that this experiment gave a certain amount of inform
he probable longevity of the typhoid bacillus under the cond
tated. It constituted a demonstration of the power of self-pu
n streams, from the fact that along the upper collecting
naintained by the city of St. Louis in Illinois River this
was not discovered, although according to the testimony very
xaminations were made. The findings of a few individual
n Mississippi River at Chain of Rocks were not positive, ina
he identification did not, from the records, appear to be a
omplete. On the assumption, however, that the identifica
orrect, the relatively insignificant number found indicated
acterium does not live long in the river water, and that the
acillus, which is beyond doubt a more highly specialized
orm, would not survive as long as the *B. prodigiosus*.
words, since *B. prodigiosus* dies off so speedily in such large
he typhoid bacillus would be less likely to survive exposure
ame conditions. (6148–6151.)

Referring to established instances where the typhoid ba
een detected in river water, the witness stated that althoug
dence which connects polluted water with outbreaks of typh
is entirely convincing both in character and mass there have
tively few instances in which bacteriologists have succeeded
ing a specific typhoid bacillus from suspected waters. Acc
actual identification are of doubtful value, especially sin
recently organisms that were similar to but by no means
with the true typhoid bacillus have been discovered in wate
citing accounts of several cases of alleged identification of the
bacillus in foreign countries and remarking on the insufficien
evidence the witness stated that the meagerness of thos
despite the thousands of examinations made by skilled bacte
in every part of the world, is in his opinion explained chiefl
relatively short duration of the life of the bacillus in wat
period elapsing between the moment of infection and the b
of the bacterial investigation is usually at least two or thre
owing chiefly to the time occupied by the incubation of th
and perhaps tardy recognition of it. Some time is also cons
the preliminary work necessary in carrying on a competent i
tion. The history of most outbreaks of typhoid fever shows
bacillus had disappeared from the water by the time a se
inaugurated, and for this reason a negative finding is the us
of such an examination. (6156–6159.)

Concerning experiments made to determine the longevity of the typhoid bacillus in water, the witness stated that examinations made with the bacillus in sterilized water and kept in glass bottles showed, among other things, that the age of the culture influences the longevity, freshly isolated stock exhibiting distinctly greater vitality than stock which had been under cultivation for some months. When introduced into sterilized Lake Michigan water, typhoid bacilli were alive under some circumstances up to ninety-three days, but did not multiply during this period. The colon bacillus, on the other hand, multiplies rapidly and has been kept alive in sterilized Lake Michigan water for two hundred and sixty-two days. There is no evidence to show that the typhoid bacillus multiplies in natural waters. On the contrary, there appears to be an overwhelming evidence that the organisms once discharged from the human body undergo a constant diminution in number. Conditions in laboratory experiments for testing the longevity of this bacillus are usually much more favorable to its life than those which it meets in nature. The witness was fully of the opinion that the organisms will live longer in pure than in polluted waters, because of the fact that in polluted waters they have to compete with various saprophytic bacteria, while in unpolluted waters they are not injuriously affected by these microbes. From what he knew of the chemical composition and bacterial content of the waters of Illinois River at various points along its course it was his opinion that the life of the typhoid bacillus introduced into Illinois River at the upper end of the drainage canal would not be more than three or four days. (6159–6161.)

The witness then testified concerning his familiarity with the physical conditions existing along the Illinois River basin, and stated that Desplaines River from Lockport to Morris has a rapid flow, but the lower part of Illinois River, especially from La Salle to Grafton, is very sluggish and consists of a series of pools, so that the body of water as a whole is almost entirely quiescent. If it were true that any of the infectious matter from Chicago persisted as far down even as Peoria, the conditions existing there and farther down the stream would be such as to bring about a further diminution in the amount of such substances. This state of semistagnation prevailing in Illinois River affords opportunity for the destruction of such infectious matter as may be introduced into the river either directly or through the tributaries. (6161–6164.)

While it is true that bacteria in a turbid water are sedimented more quickly than in a clear water, the turning into Illinois River of the clear water from Lake Michigan does not interfere with sedimentation, because in that portion of Illinois River where most sedimentation occurs the amount of suspended matter introduced into the water from the tributaries and entering the river directly is sufficient

to effect the same degree of sedimentation that would occur if the present amount of dilution with water from Lake Michigan were absent. Therefore while the introduction of Lake Michigan water might probably interfere with sedimentation in the upper part of the river it would have no such effect in the stretch of the stream from La Salle to Grafton. (6165–6166.)

Concerning the effect of dilution on the purification of streams, the witness stated that although dilution does not cause any actual destruction of infectious material it does diminish the danger of infection arising from the drinking of such water. If, for example, infectious material were introduced into water to such an extent that each tumblerful contained one typhoid bacillus and this water were diluted with nineteen times its bulk of pure and uninfected water it would then be true that out of one hundred tumblerfuls of this mixture only five tumblerfuls would contain typhoid bacilli instead of the whole one hundred, as was originally the case. In other words, the effect would be the same as if 95 per cent of the typhoid bacilli perished. In this way dilution unmistakably diminishes the danger from infection. Such dilution as is turned into Desplaines River from the drainage canal has, however, little effect on the infectious quality of the water in Illinois River at Grafton, because, in the opinion of the witness, the infectious bacteria in the Chicago sewage would have perished long before the mouth of Illinois River would be reached. (6167–6168.)

The witness then said that Professor Sedgwick, in his testimony recorded on page 2207 of the record, made a misquotation from the report of the river commissioners of Great Britain published in 1874 giving their statement as "there is no river in the United Kingdom long enough to purify itself from any sewage admitted to it, even at its source," whereas the statement in reality was, "It will be safe to infer * * * that there is no river in the United Kingdom long enough to effect the destruction of sewage by oxidation." The witness explained that there was a material difference in the two statements, because at the time the aforesaid report was published the knowledge of sanitarians regarding the quality of a water was based on chemical rather than on bacteriological data; practically nothing was known then concerning the elements in sewage that imparted to it its dangerous character. It had been determined empirically that a certain relation exists between the oxidation of sewage and the loss of its dangerous qualities, but it was not known what this relation was nor on what it depended. The modern conception of the purification of a sewage-polluted stream is based on the disappearance and destruction of disease-producing bacteria. There is, therefore, a wide difference between stating that the purification of a stream is effected within a certain distance and that the destruction of sewage

by oxidation is effected within a certain distance. It does not follow that because complete destruction by oxidation of the organic matter in a polluted water does not occur within a specified distance, the real purification, namely, the destruction of dangerous bacteria, may not be accomplished within that distance. The process of nitrification or oxidation and the processes leading to the disappearance of dangerous bacteria do not always run a strictly parallel course, either in sewage tanks or polluted rivers. (6172–6174.)

The witness then took up the discussion of an elaborate series of experiments made to determine the longevity of the typhoid bacillus under natural conditions in the water of the drainage canal and of Illinois River. The experiments were conducted with the cooperation of Professor Russell, of the University of Wisconsin, and Professor Zeit, of the Northwestern Medical School. The serious and misleading effect on the longevity of the typhoid bacillus produced by laboratory conditions had impressed itself upon the witness, and with a view to removing this objection, receptacles were planned for imprisoning the bacilli in the water of the drainage canal under normal conditions of life and temperature.

Five different bodies of water were selected for these experiments, namely, Lake Michigan, Chicago River, the drainage canal at Lockport and at Robey street, and Illinois River at Averyville. Professor Zeit carried on the experiments with Lake Michigan and Chicago River water, Professor Russell undertook those with the water of Illinois River at Averyville, and the witness conducted those on the drainage canal. Parchment sacks were employed instead of glass tubes. These sacks had a capacity of about 800 c. c., and when suspended in the water by floats permitted the passage of certain substances in solution, but did not allow the bacteria to pass through their walls. The conditions to which the typhoid bacilli introduced into the sewage in these sacks were subjected are almost precisely those prevailing in nature, inasmuch as the bacteria inside and outside of the sacks can not pass through the walls, and yet they are subjected to the action of the toxic products and the saprophytic microbes in the sewage. The sacks were fastened to the points of glass tubes about 6 inches in length and were sealed with a mixture of tallow and rosin. They were then weighted so as to swing freely in the water when filled with sewage and suspended in a framework covered with a wire screen that permitted free circulation of the outside water. This frame was made of fine strips of wood, and was 4 feet long and 3 feet wide by 3½ feet deep. The bottom, top, and lower five-sixths of the sides and ends of this frame were covered with wire screen. The upper 6 inches of the sides and ends were of 1-inch pine fencing. The top opened with a hinge and was fastened in place by a hasp and padlock. It was balanced in such a way that it floated with the water

level up to the height of the lower margin of the upper solid portion of the body. The part above the water was thus of boards and served to break the effect of the waves over the sacks. The witness was confident that the water within the frames differed in no essential way from that in the open channel. The sacks were tested for cracks or defects before they were taken from the labratory and again when they were filled in the field. To the lower end of each sack a small weight was attached, which served to keep it in an upright position in the water. A cord was also fastened to the lower end, by means of which the sack was brought to the surface of the water and the contents agitated at the time of taking samples. In carrying forward these experiments three cultures were employed, designated as *x*, *y*, and *z*, all taken from patients suffering from the disease. They were therefore in an active and virulent condition. Into the sacks was introduced a quantity of sewage, together with a strong culture of the typhoid bacilli. Sixteen such sacks were placed in the Chicago drainage canal at Robey street and 12 at Lockport. Other sacks which were not inoculated with typhoid bacilli but contained samples of raw sewage taken from the canal at the respective points were used for parallel experiments. Samples of water from these control sacks were placed at frequent intervals and examined as to their bacteriological content. After the culture sacks were inoculated and set in place samples were collected from them in sterilized glass bottles, with all proper aseptic precautions, and accurately measured quantities were mingled with sufficient nutrient media of various kinds, and when the growth had sufficiently developed were examined for the identification of the typhoid bacillus. The results for the two stations in the drainage canal are included in Table 78. The full discussion of these important experiments occupies pages 6180–6238 of the record.

TABLE 78.—*Results of experiments with Bacillus typhosus infection in Chicago drainage canal, 1903.*

Station.	Date.	Bacteria per cubic centimeter (initial count).			
		Sewage bacteria.	Colon bacilli.	Streptococci.	B. typhosus infection
Lockport	October 5-14	110,000	4,000-6,000	1,000	12
Do	do	110,000	4,000-6,000	1,000	
Do	do	110,000	4,000-6,000	1,000	
Do	October 14-27		1,000	2,000	30
Do	do		1,000	2,000	1
Do	October 17-27		1,000	2,000	300
Robey street	October 9-23	390,000	4,000-6,000	2,000	11
Do	do 9-23	390,000	4,000-6,000	2,000	
Do	do	390,000	4,000-6,000	2,000	18
Do	do	390,000	4,000-6,000	2,000	
Do	October 18-23	113,000	1,000	2,000	25
Do	do	113,000	1,000	2,000	16
Do	October 25-November 4	240,000	1,000	1,000	285
Do	do	240,000	1,000		285
Do	do	240,000	1,000		857
Do	do	240,000	1,000		857

TABLE 78.—*Results of experiments with Bacillus typhosus infection in Chicago drainage canal, 1903*—Continued.

Station.	Typhoid bacilli found after inoculation.																
	10 minutes.	1 hour.	20 hours.	28 hours.	1 day.	2 days.	3 days.	4 days.	5 days.	6 days.	7 days.	8 days.	9 days.	10 days.	11 days.	12 days	14 days.
Lockport					0	0	0		0		0		0				
Do					0	0	0		0		0		0				
Do					0		0		0		0						
Do							0		0	0		0		0			
Do							0		0								
Do	63					0	0		0		0			0			
Robey street								0		0	0				0	0	0
Do						0		0			0						
Do								0		0	0				0	0	0
Do						0		0		0							
Do						0	0		0								
Do						0	0		0								
Do		41	21	46		1	0	0	0	0	0	0					
Do							0	0	0	0	0	0	0				
Do			20	43		9	0	0	0	0	0	0	0				
Do								0	0	0			0				

From the results of the experiments above recorded and those conducted by Professors Russell and Zeit, the witness submitted the following conclusions: Experiments under conditions closely simulating those in nature indicate that the typhoid bacillus introduced into unsterilized Lake Michigan water does not survive for a period longer than four days after such introduction. It is probable that specially resistant individual cells may survive longer, but in any case the maximum period would be eight to ten days. The experiments in the drainage canal indicate that the bacillus was not isolated after two days, except in one anomalous case, in which three typhoid bacilli were isolated on the tenth day from a single plate in a single sack. The reasonable explanation for this, according to the witness, was that at times when the contents of the sack were heavily infected, during the process of tilting and agitation some particles in the sewage to which typhoid bacteria were adhering were deposited and became dried upon the walls of the sack above the water line and were subsequently washed off and dropped into the water of the sack. Taking into consideration all the experiments made in the drainage canal, the witness was of the opinion that the typhoid bacilli could not live for a period longer than four days after infection. The experiments in Illinois River led him to believe that they would not live in that stream under natural conditions for a period longer than five or six days. Summing up, the witness stated that specific infection of typhoid fever discharged into the drainage canal might live as long as three or four days after leaving the body of the pollution, but that at any rate it would perish long before Averyville was reached. (6238–6241.)

The witness then cited experiments made by Dr. William G. Savage, of University College, Cardiff, Wales, in which it was shown that the colon bacillus lives for some time in soils but disappears as time goes on, the ordinary soil organisms invading the material and taking the place of the colon bacillus. It is more resistant than the typhoid bacillus, and therefore it is a fair assumption that the latter would rapidly die out in soils. (6241.)

The witness stated that the experiments above outlined show that the colon bacillus and sewage streptococci die out rapidly in polluted streams, and attributed the death of the typhoid bacillus in such water to the poisonous action of the products of other microbes, and this is the reason why the germ will not live as long in polluted as in pure water. He then expressed the opinion that the life of the typhoid bacillus would not continue any longer in the sediment of a polluted stream than in the water of that stream, because in the sediments the germs are in very much the same surroundings that they would be in the water, except that it is fair to assume that the organic matter is more abundant on the bed of the stream in the sediments. This condition would encourage the growth of saprophytic bacteria, and therefore the toxic products fatal to the typhoid germ would be in more concentrated form. There is a difference in the conditions that prevail in moist soil and those in the sediment of a running stream. In the former the bacilli are not exposed to the action of toxic products for the reason that such products can not act on the bacillus through the intervening air space or through the interstices of the soil. A continuous layer of fluid is needed for the diffusion of these toxic products, and unless the typhoid bacilli are in contact with them the conditions in ordinary damp soil are different from those prevailing in the sediment at the bottom of a river. Therefore the time that the typhoid bacilli will live in moist soil furnishes no criterion for its longevity in the sediment of a running stream. (6242–6244.)

Referring to the case in which the presence of typhoid germs was demonstrated in the mud of Lake Geneva, cited in the testimony of George W. Fuller, the witness stated that considerable doubt had been thrown on the work of the observer because his methods of identification were not satisfactory. He further said that he knew of no experiments or observations which demonstrate that this germ can live in the sediment of a running stream for a period up to a year, as stated by Mr. Fuller. (6246–6248.)

With reference to the statement made in the testimony of Professor Sedgwick that typhoid fever sometimes prevails in a city drawing its supply of water from a reservoir of a storage capacity equal to thirty days' consumption, the witness stated that it is not true that in such cases all the water pumped into this reservoir would remain there for a period of thirty days. In point of fact, some of it might

be drawn from the reservoir within a very short time after its entrance therein. It does not follow that because a reservoir or settling basin holds a thirty days' supply all the typhoid bacilli introduced therein remain for thirty days. (6252.)

The witness laid special stress on the importance of the interpretation of vital statistics. It is not a matter of indifference how the figures so collected are viewed by statisticians. Statistical pitfalls are numerous, and certain fallacies of interpretation exist, the introduction of which may vitiate any conclusion drawn from figures that are in themselves exact. For example, it is commonly assumed that the death rate of a city is a correct measure of its healthfulness. The death rate among individuals of different ages and nationalities varies so much that a statement of deaths without regard to age, sex, or distribution of racial characteristics does not afford any helpful information and is frequently misleading. A community having a large percentage of infants or of aged persons would have a larger number of deaths per thousand than a community having a larger proportion of individuals of more resistant age; yet the two places may be equally healthful. It is well known, too, that certain races of mankind manifest weakness or lack of resistance to various diseases. For example, persons of Irish parentage are much more liable to consumption and pneumonia than Russian and Polish Jews. Therefore in making a statement of death rates from these two diseases in any city account should be taken of the proportion of each of these races involved in the estimate. (6260–6261.)

The method of expression of the fatality rate of any particular disease according to the mortality-percentage method described in the testimony of Messrs. Sedgwick and Fuller frequently fails, in the opinion of the witness, to give correct information as to the progress of the disease. Quoting from Newsholme, Vital Statistics, page 186, he gave the following example:

> Suppose a town of 100,000 with 2,000 annual deaths, of which 500 are caused by phthisis. Here the general death rate is 20 per 1,000; the death rate from phthisis is 5 per 100 living, and the deaths from phthisis form one-fourth of the total deaths. In another town having the same population the total deaths are 4,000, and therefore the death rate 40 per 1,000 inhabitants; the deaths from phthisis are 1,000, and therefore the death rate from phthisis is 10 per 1,000; but the proportion of the phthisical to the total mortality is one-fourth, as before. In the second town, however, there is by the latter test apparently no worse condition, so far as phthisis is concerned, than in the first, though matters are really twice as bad. (6261–6262.)

With reference to the value of chemical and bacterial data in water examination, the witness was of the opinion that such analyses furnish important evidence, and that while they often supplement and confirm the results of observations they also at times reveal conditions that mere ocular inspection would fail to bring to light. It is sometimes true that chemical and bacteriological data are the only data

obtainable. In the study of the self-purification of streams such analyses afford a material aid in determining the rate and extent of the process of purification and make it possible to trace the successive changes that take place in the amount and condition of the organic matter. (6266–6267.)

Assuming that the reports of the St. Louis board of health show an apparent increase in typhoid fever during the years 1900 to 1903 inclusive, the witness stated that he did not regard it as a justifiable conclusion that the apparent increase was due to any infectious matter passing into the sewers of Chicago and thence to the St. Louis intake by way of Illinois and Mississippi rivers. An increase in the infection of Mississippi River water from points near at hand would seem to afford a more satisfactory explanation. The rural population on the watershed is an important factor to be considered, because typhoid fever is far more prevalent in rural than in urban districts. (6270–6275.)

The witness then compared the records of typhoid fever by months from 1890 to 1903, inclusive, in Chicago and St. Louis, and stated that he was unable to discover any relation between the monthly death rates in the two cities. The month showing the largest number of deaths in Chicago precedes the maximum in St. Louis by eleven months in 1892, by eight months in 1903, by six months in 1891, by five months in 1896 and 1898, by three months in 1899, and by two months in 1902. The Chicago maximum coincides with the St. Louis maximum in five years—namely, 1893, 1895, 1896, 1897, and 1900. The minimum monthly typhoid fever in Chicago precedes the minimum in St. Louis in five years—namely, 1891, 1893, 1898, 1900, and 1902, while the Chicago minimum coincides with the St. Louis minimum in 1890 and 1892 and follows it in 1894, 1895, 1896, 1897, 1901 and 1903.

The witness stated that he would expect in general that if the typhoid-fever conditions in St. Louis were dependent on those in Chicago, a large number of deaths from typhoid fever in the latter city would be followed within three or four months by an increase in the number in the former. No such relation appears, and therefore in his judgment the typhoid conditions in St. Louis are unaffected by those in Chicago. (6279–6281.)

The witness then presented some comparisons of the readings of gage heights in Illinois River at Kampsville and the death rate from typhoid fever in St. Louis, the object being to show that the contentions of the plaintiff concerning the effects of floods in Illinois River in raising the typhoid rate in St. Louis were not true. As a result of these comparisons the witness stated that in 1899 high water occurred at Kampsville in March and low water in September, while the maximum typhoid death rate in St. Louis occurred in November and the minimum in May. Again, in 1900 the high-water period was

March and the low-water period in January, while the maximum typhoid fever occurred in St. Louis in October and the minimum in April and May. In 1901 high water occurred in April and the maximum typhoid fever rate in October, while low water occurred in October and the minimum typhoid in April. In 1902 high water occurred in July and low water in January, while the maximum typhoid occurred in October and the minimum in June. During July to November, inclusive, 1902, Illinois River averaged twice as high as during the same period in 1901, yet the typhoid-fever rate in St. Louis was almost exactly the same in the two years. From a detailed comparison of the entire record the witness stated that he was unable to discover any connection between the stages of water at Kampsville and the rate of typhoid at St. Louis, and he therefore concluded that the contention that high water in Illinois River washed down the infected matter from Chicago more quickly and resulted in high typhoid in St. Louis was unfounded. (6282–6284.)

The witness then discussed the characteristics of typhoid and malarial fevers at some length and stated that the diseases ordinarily termed intermittent fever, remittent fever, typho-malarial fever, congestive and continuous fevers are not distinct types, but that most of the infections designated by these terms are true typhoid or malaria, and in his opinion the deaths so classed should be transferred bodily to the column of deaths from typhoid fever, since malaria in temperate countries is rarely fatal. He further stated that he found in the records of the health department of St. Louis a very considerable number of deaths under these headings and believed that they were all genuine typhoid, and in his opinion no city in the United States has so large a death rate from genuine malaria as would be indicated by the official records of St. Louis. He then summed up the statistics for typhoid fever and the poorly defined disorders above noted, as shown in Table 79. (6287–6294.)

TABLE 79.—*Deaths from typhoid and so-called malarial fevers in St. Louis, 1895–1903, inclusive.*

Month.	1895.		1896.		1897.		1898.		1899.		1900.		1901.		1902.		1903.	
	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.	A.	B.
January	12	10	4	13	7	5	4	6	10	4	19	6	8	5	14	5	15	4
February	3	7	4	10	9	5	6	10	7	8	5	3	14	0	16	6	15	1
March	3	8	3	6	7	11	7	9	4	6	16	9	11	4	11	9	20	4
April	7	7	4	11	4	13	6	8	5	6	4	7	4	7	14	3	17	4
May	6	9	9	10	7	8	2	8	2	12	4	7	8	7	11	8	15	8
June	6	14	6	7	9	18	7	10	5	8	8	12	16	9	7	4	18	8
July	9	8	13	23	10	17	9	13	9	18	15	9	13	15	14	12	27	10
August	17	15	29	34	18	20	(9)	(14)	6	30	20	20	31	5	26	7	37	10
September	9	32	13	27	17	31	14	18	16	28	13	20	24	9	21	16	42	17
October	15	24	9	20	17	24	12	12	15	16	30	9	32	11	32	17	29	17
November	13	8	7	14	15	13	7	13	32	8	15	3	27	5	31	9	24	3
December	7	13	5	2	5	5	12	13	20	4	19	7	20	3	25	6	31	5

A. Typhoid fever.
B. Remittent, intermittent, typho-malarial, congestive, and simple continued fevers.

The witness stated that the above table shows a close parallel between the number of deaths reported from the two causes. During the period July to October the number of deaths reported from both causes is high, while during April and May the number was low. During the latter part of the period an interesting change is noted. For the first five years the number of deaths under the heading B was greater than under A, but beginning with 1901 the reverse is true, showing that during the last four years there had been a transfer from column B to column A, the effect being to diminish the number of deaths from the so-called malarial fevers and increase the number from typhoid. The witness then presented Table 80, which is in part a summary of Table 79. (6294–6296.)

TABLE 80.—*Deaths from typhoid fever and reported deaths from remittent, intermittent, typho-malarial, congestive, and simple continued fevers in St. Louis, 1890–1903.*

Year.	Deaths from typhoid.	Deaths from other fevers.	Total.	Year.	Deaths from typhoid.	Deaths from other fevers.	Total.
1890	140	226	366	1897	125	172	297
1891	165	216	381	1898	95	134	229
1892	441	326	767	1899	131	148	279
1893	215	284	499	1900	168	112	280
1894	171	179	350	1901	198	80	278
1895	107	155	262	1902	222	102	324
1896	106	177	283	1903	288	91	379

The witness pointed out the fact that the above table shows that during the first ten years the number of deaths reported from typhoid fever was generally less than those from remittent fever, etc., but during the last four years the situation is reversed, and it is evident that some cause has been at work tending to produce a more accurate diagnosis on the part of the physicians. He believed it reasonable to suppose that the letters issued by the health commissioner to the physicians in 1900 and 1901, calling attention to the opening of the drainage canal and the necessity for reporting typhoid cases in the city, had caused them to pay closer attention to diagnosis, which had resulted in the marked change in reporting deaths. Citing so-called malarial records of other cities, such as Chicago, Albany, and Baltimore, the witness stated that there was a general correspondence by months and years with what had been noticed in the St. Louis record, namely, that the proportion of deaths from malarial fevers has been lower during recent years than previously, while that from typhoid has been higher. In support of his contention that the deaths from so-called malarial diseases should be placed in the typhoid column, he cited the experience of Albany, where a sand filter was put into operation in September, 1899. During the ten years previous to this date 777 deaths were reported from typhoid fever, or an annual average of 86, and during the four years after the

installation of the filter, the number of deaths amounted to 106, or an annual average of 26. An exactly similar decline was noticed in the number of deaths reported from malarial diseases. Prior to the opening of the filter, these amounted to 61, or an annual average of 7, while during the four years since the filter was opened only 2 deaths had been reported, or an average of one-half. In the opinion of the witness, the inference was plain that both the above reported causes of death had been affected by the opening of the filter and only one conclusion could be drawn, namely, that the deaths reported as occurring by reason of malarial diseases were really genuine typhoid cases. Summing up all of the evidence, including that of the so-called malarial diseases, the witness stated that he was of the opinion that the average death rate from typhoid fever in St. Louis had been less during the four years from 1900 to the date of the testimony than previous thereto—excluding the year 1892, during which occurred the great epidemic—and that no portion of the typhoid fever mortality occurring in St. Louis since January, 1900, could be attributed either directly or indirectly to the effluents from the Chicago drainage canal. (6296–6309.)

With reference to the statement of Professor Sedgwick that inasmuch as typhoid germs coming from Chicago sewage are deposited in large quantities in the lakes and slack-water portions of Illinois River above Peoria, flood conditions such as would scour these deposits from the bed of the stream would cause the water leaving Lake Peoria to contain at times more infectious and dangerous pollution than is present in the diluted sewage entering the river at the foot of the drainage canal, the witness asserted that typhoid fever germs live so short a time under such conditions that there is no danger that the water leaving Lake Peoria can at any time contain more infectious material than exists in the diluted sewage flowing through the foot of the drainage canal. On the contrary, he was satisfied that there is a much smaller proportion in the water of Lake Peoria than in that of the canal. It is possible that where deposits of sewage matter are fresh, as they are in the bed of Chicago River, the sudden flushing out of such a stream may lead to an outbreak of typhoid fever within two or three days' distance from such deposits; but the witness knew of no instance where an epidemic of typhoid fever had been traced to the removal or flushing out of such sewage matter that had been allowed to remain undisturbed for a period of several weeks without receiving any addition of fresh material. In this connection, he declared that the cause of the epidemic at Detroit cited in the testimony of Messrs. Sedgwick, Whipple, Williams, and others had not been established beyond a reasonable doubt as coming from Black River at Port Huron. (6316–6319.)

On the assumption that an increase in typhoid fever since the opening of the drainage canal had actually occurred, which appeared to the witness to be contrary to the facts, it would be more reasonable to attribute such an increase to other causes than the canal, such as an infection of the water supply at some point nearer the intake, infection of the milk supply, or some other factor. (6323.)

It was the judgment of the witness that the water supply of St. Louis during the period from 1895 to 1899 was not satisfactory, because of the great amount of typhoid fever in the city, together with the typho-malarial and other so-called malarial troubles which should have been classed as typhoid. All these being taken into consideration, the rate during the years mentioned was much higher than it ought to be in a city having a pure and satisfactory water supply. (6327.)

The witness stated that it was impossible to draw a fair comparison between the conditions on the Potomac River between Cumberland and Washington and those on the streams between Chicago and St. Louis. The relatively rapid flow from Cumberland to Washington and the relatively short space of time required to travel this distance represent a very different set of conditions than those prevailing in Illinois River, because in the lower portion of the Illinois the current is sluggish and the time required for a body of water to pass very much greater than in the Potomac. (6334.)

Chicago pollution is manifest at the mouth of Illinois River chiefly in the increased amount of chlorine and nitrogen present in the water, but so far as the original polluting matter and pathogenic bacteria are concerned, there are no grounds for adopting the opinion that these substances persist in their original condition as far down as Grafton. It is quite possible that some of the very stable compounds introduced at Chicago may reach Grafton, but such compounds have no sanitary significance. (6336.)

The dams and slack-water basins in the Illinois River materially facilitate the process of sedimentation, but the removal of all the dams would not materially affect the purification of the Chicago sewage, because the elimination of the typhoid bacilli takes place in the upper portion of the stream. Such removal might, however, have some effect in retarding the purification of dangerous materials discharged by various communities in the lower stretches of the river. (6338-6339.)

CROSS-EXAMINATION.

The witness stated that in his opinion the best evidence of the purity of a water supply is the effect which it produces on the health of the community using it for domestic purposes. (6345.)

While nothing is definitely known as to the number of typhoid bacilli necessary to produce typhoid fever in man, it is well known

through experimental work on animals, that a single germ is rarely able to produce infection. In all cases of inoculation not one germ alone but many hundreds must be used in order to produce infection, even when these bacteria are introduced into the most delicate portions of the body. Reference was made to a case in which a laboratory worker attempted suicide by swallowing typhoid cultures. Several tubes of virulent culture produced only a mild attack of the disease, and while it is true that this person may not have been susceptible, there are very few data on which to base an opinion concerning susceptibility. Persons between the ages of 15 and 35 are more liable to typhoid fever than younger or older persons, but there is little information showing on what this variation in susceptibility depends. (6350–6351.)

With reference to the significance of sanitary analyses, the witness stated that there are cases in which light may be thrown on the sanitary quality of a water by the chemical examination, when the bacterial count at the time the examination is made fails to give information. For example, well water is often found to be high in chlorine and nitrates, which are indicated by the conditions to have originally come from sewage pollution. The number of bacteria in such a water may be low at the time the examination is made, but owing to the dangerous character of the surroundings the water would be condemned by the prudent sanitarian, although the bacterial count had not been high, inasmuch as it would be subject at any time to another influx of pollution, which would then be shown by the bacterial count. In the light of all the experience of the witness in the chemical examination of water, the amount and rate of nitrification in Illinois River between Lockport and Grafton are such as have been found in the experience of water analysts to accompany the disappearance of disease-producing elements, and while it is not possible to establish absolutely from the results of chemical examinations that any point where samples had been taken is free from disease-producing elements, such analyses afford a certain kind of evidence that must be weighed in forming judgment as to the sanitary quality of the water. (6359–6363.)

The cross-examiner then pointed out several instances in which the results of the witness' chemical examinations and those of Professor Palmer, made on samples of water taken at the same time and from the same point in the river, varied widely. The witness admitted these variations, but stated that the determinations are so delicate that even experienced water analysts obtaining samples of water under the same conditions would be expected to arrive at results that would differ, but such variations of 50 or even 100 per cent have no sanitary importance. The averages of a considerable series of analyses constitute the important factor, and little weight is attached to a single determination. (6366–6369.)

The witness stated that he did not wish to put himself in the position of recommending the introduction of sewage of any degree of staleness into a river from which a public water supply was immediately taken. The esthetic as well as the sanitary side is to be considered, and although he had stated that two days was about the limit of longevity of the typhoid bacillus in sewage, this time ought to be doubled or trebled to insure safety. It was his firm opinion that if the sewage contained in the Chicago drainage canal was from four to six days old typhoid bacilli would not be alive in it. (6375.)

LUDWIG HEKTOEN.

Prof. Ludwig Hektoen, called as a witness on behalf of the defendants, stated that he was a physician and surgeon, graduated from the College of Physicians and Surgeons in Chicago in 1887, had made a specialty of pathology in various hospitals and institutions in Cook County, Ill., and had studied extensively in Europe. His testimony, given on pages [illegible] of the record, was in general a confirmation of that part of the testimony of Professor Jordan relating to the typhoid and malarial death rates in St. Louis and the probable identity of the two classes of diseases. He expressed the opinion that under that interpretation there had been no increase in typhoid in St. Louis.

H. L. RUSSELL.

DIRECT EXAMINATION.

H. L. Russell, a witness called in behalf of the defendants, stated that he was in charge of the department of bacteriology in the University of Wisconsin, having occupied that position since 1893. He had received his bachelor's degree from that university in 1888, remained there as fellow in bacteriology until 1890, and then studied in Koch's Institute in the University of Berlin, in the zoological station at Naples, and in the Pasteur Institute at Paris. He returned to America in 1891 and took the degree of doctor of philosophy at Johns Hopkins University. Since 1894 he had been bacteriologist of the Wisconsin State board of health, and in that capacity, as well as in a private capacity, had had to do with the analyses of waters from a bacterial point of view for sanitary purposes. In connection with this work he had made examinations of all the waters submitted for public analysis in the State and had been specially engaged in the examination of the water supplies of Superior, Ashland, Marinette, Merrill, Stevens Point, Wausau, Eau Claire, Portage, Green Bay, Beloit, Baraboo, Wis.; Menominee, Mich., and Dubuque, Iowa. He had studied outbreaks of typhoid fever and made investigations of the subject at Baraboo in 1901 and at Ashland, Superior, Menominee, and Marinette. He professed to have

an extensive acquaintance with the literature bearing on typhoid fever epidemics and other water-borne diseases. (6467–6469.)

The witness stated that he had examined and studied the bacterial and chemical analyses of the waters of Lake Michigan, the drainage canal, and Desplaines, Illinois, Mississippi, and Missouri rivers, as made and introduced into the testimony by Professors Jordan, Gehrmann, Palmer, and Burrill. In addition to this, he made a journey in September, 1903, from Chicago to St. Louis by way of the above-named water courses, which had given him special opportunities for the physical examination of those streams. (6469–6470.)

With reference to the *Bacillus prodigiosus* experiment, an account of which was introduced into the testimony by Doctor Ravold, the witness stated that, assuming all the premises to be true and taking into consideration all the knowledge which he possessed concerning the distribution of this organism under normal conditions, he was of the opinion that the experiment did not in any way throw light on the probable longevity of the typhoid bacillus as measured by that of *B. prodigiosus*, and he was led to believe it to be highly improbable that the organisms reported to have been found in the water taken from the intake tower at Chain of Rocks were the same or were derived from the organisms placed in the water of the drainage canal. The witness based this conclusion on the fact that a series of examinations made of samples taken from Illinois River at Lockport, Joliet, Peoria, and Grafton between November 7 and December 15, amounting in all to 1,752 samples, and also of samples taken from the intake tower at Chain of Rocks and from the laboratory tap in St. Louis between November 20 and March 1, amounting in all to 3,120 samples, failed to reveal the presence of *B. prodigiosus* until twenty-eight days had elapsed from the time the cultures were placed in the drainage canal. If the organisms reported to have been isolated from the waters of Illinois River at Grafton and Mississippi River at Chain of Rocks had been the same as those deposited in the canal, or their progeny, it would have been natural to expect that in the numerous preceding analyses that had been made organisms of this species would have been found, as there is reason to believe that the flow of water from the canal through Illinois River to St. Louis would not have consumed a period of twenty-eight days. It is not uncommon to find in the water of this region organisms which possess characteristics similar to those of *B. prodigiosus* by reason of the red pigment that they produce when grown upon the ordinary nutrient media, and which therefore might be mistaken for *B. prodigiosus* unless the characteristics of the germs isolated were studied in detail. (6473–6476.)

The witness then described various pathogenic bacteria and other methods of identification, and stated that the typhoid bacillus is

capable of retaining its vitality in soil for a varying period of time, depending on the influences to which it is subjected. When deposited in soil by burial the organism rapidly loses its vitality, so that at the expiration of a short period, measured by a few days, it can no longer be detected in the upper layers of the soil. When the soil is moist and the organism is deposited in typhoid dejecta, the germ is capable of retaining its vitality for a longer period of time, which may be measured by months. When deposited in water the life of the bacillus is materially shorter than in soil. Where it is brought into contact with a medium containing normal saprophytic bacteria, such as would naturally be found in sewage or polluted waters, the vitality of the typhoid germ is greatly impaired and its longevity would not normally be more than three or four days; but in waters of a great degree of purity, where saprophytic life is not so abundant, the longevity would be increased, so that it may possibly be found at the end of one or two weeks. (6477–6481.)

The witness then described an extensive series of experiments conducted by him to determine the longevity of the typhoid organism. These experiments indicate that the germs of typhoid fever are capable of retaining their vitality for a period of time measured by months in water which is ordinarily pronounced pure and which has first been sterilized by heat and thus deprived of its ordinary germ life and possibly of the metabolic products of bacterial activity. When, however, the typhoid organism is introduced into such water that has been deprived of its bacterial life by filtration and under conditions where soluble products of bacterial growth remain in the water, the life of the germ is considerably shorter than it is in water sterilized by heat. (6481–6482.)

In the opinion of the witness the conditions under which laboratory experiments have been performed to determine the longevity of the typhoid organism are, as a rule, more favorable for the prolongation of vitality than natural conditions, because when the typhoid organism is exposed under natural conditions—in flowing waters, for example—it is subjected to a number of factors of a detrimental character which often can not be readily simulated under laboratory conditions. (6482.)

From his knowledge of the conditions in the waters of the drainage canal and Illinois River the witness gave it as his opinion that the longevity of the typhoid organism in those waters would not be greater than three to four days, because of the great number of conditions exercising prejudicial effects on its vitality. He stated that this assertion had been proved by experiments in which cultures of the typhoid organism were placed in celloidin sacks, which, being germ tight, would not permit the passing out or in of any organism but which would, on the other hand, permit the passage of the soluble

products of the growth of these organisms. These sacks were placed in cultures made of nutrient material, to which was added various other kinds of material containing divers forms of saprophytic bacteria. Under such conditions bacterial growth was abundant in the outside medium, but the organisms inside of the sacks were unable to grow and in many instances were actually killed. (6483–6484.)

The dams in Illinois River, especially in the lower reaches, where the normal fall is slight, have a considerable effect in producing marked sedimentation of suspended matter in the water, and such sedimentation carries to the bottom much of the bacterial life, thus purifying the water. Inasmuch as the specific gravity of bacteria is only a trifle above that of water, the sedimentation of such organisms must necessarily accompany the sedimentation of suspended matter, which is at its maximum under quiescent conditions. It is extremely improbable that sufficient clear water from Lake Michigan could be discharged through the drainage canal to interfere with the normal sedimentation taking place in the river behind dams and in other practically quiescent portions of the channel. (6486–6489.)

Dilution of any polluted water with any pure water greatly diminishes the danger of infection from the use of such water. The infection of the human system from disease bacteria requires in some cases a simultaneous introduction of more than one specific organism. When water which is infected with such bacteria is diluted with pure water the danger which might arise from the ingestion of such water is diminished. Therefore, on the assumption that the danger of infection from sewage comes from the presence of pathogenic bacteria, a dilution of the sewage would diminish the number of bacteria of a specific kind per unit quantity of water. Thus the discharge of pure water from Lake Michigan into Illinois River, through the drainage canal, greatly minimizes the danger of infection which might come from the Chicago sewers, and when considered from the standpoint of dilution alone the injection of Lake Michigan water into Illinois River must be beneficial. Considering the conditions in Illinois River with reference to sedimentation and dilution and all other observable factors which permit chemical and bacterial changes in the sewage, as revealed by the analytical results presented by the defendants, the witness did not believe that the sewage of Chicago could have any material effect on the waters of Mississippi River, except possibly to increase the amount of such undissolved salts, as chlorine, which are not taken out of solution and which would therefore find their way downstream, and thus increase the chlorine content of the waters of Mississippi River as it passes the shores of Missouri. Basing his opinion on results of investigations on the longevity of typhoid-fever bacilli in natural waters, the witness stated that dangerous pollution in Chicago sewage could not exert any influence on the character of

the waters of Illinois River at its mouth, because it had been shown that organisms capable of causing typhoid fever will not live in the waters of Illinois River for a sufficient period of time to be carried from Chicago to Grafton. (6489–6494.)

The witness then gave an account of his joint experiments with Professors Jordan and Zeit for the purpose of determining the longevity of typhoid bacilli by confining them in impermeable sacks and exposing them in the waters of the Chicago drainage canal and Desplaines River. The technique of these experiments is described in the testimony of Professor Jordan (pp. 235–236) and will not be repeated here. Professor Russell's account can, however, be found on pages 6496–6509 of the record. His work was carried on at Peoria. The results are discussed on pages 6509–6516 of the record and are reported in tabular form below.

TABLE 81.—*Results of longevity experiments with typhoid bacilli in water of Illinois River at Peoria by the impermeable-cell method.*

No. of laboratory sack.	Strain of culture used.	Number of typhoid organisms per cubic centimeter inoculated.	1st day.		2d day.		3d day.		4th day.		5th day.		6th day.		7th day.	
			Number of colonies flashed.	Number of typhoid colonies.	Number of colonies flashed.	Number of typhoid colonies.	Number of colonies flashed.	Number of typhoid colonies.	Number of colonies flashed.	Number of typhoid colonies.	Number of colonies flashed.	Number of typhoid colonies.	Number of colonies flashed.	Number of typhoid colonies.	Number of colonies flashed.	Number of typhoid colonies.
1	X	1,000	12	1	....	....	9	0	....	....	11	0	....	....	....	....
2	X	2,000	....	....	....	....	....	....	8	0	....	....	....	....	....	....
3	X	4,000	....	....	....	....	....	....	....	....	....	....	12	0	....	....
4	X	10,000	....	....	....	....	....	....	13	0	3	0	....	....	8	0
5	X	20,000	6	0	....	....	13	2	....	....	9	0	8	0	7	0
6	Y	1,000	8	3	....	....	6	2	....	....	....	....	....	....	....	....
7	Y	2,000	....	....	....	....	....	....	9	0	....	....	....	....	....	....
8	Y	4,000	....	....	....	....	....	....	....	....	....	....	8	0	....	....
9	Y	10,000	....	....	....	....	....	....	11	0	....	....	....	....	7	0
10	Y	20,000	8	4	....	....	16	10	....	....	18	0	....	....	6	0
11 [a]	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
12	Z	540	3 [b] / 17	3 / 15	12	6	....	....	....	....	8	0	....	....	....	....
13	Z	540	....	....	....	....	....	....	....	....	....	....	....	....	3	0
14	Z	5,400	3 [b]	3	....	....	....	....	....	....	....	....	....	....	1	0
15	Z	10,800	15	14	13	6	....	....	....	....	12	0	....	....	....	....
Number of colonies daily examined from all sacks			72	....	25	....	44	....	41	....	61	....	28	....	32	....
Number of typhoid colonies found on successive days			....	43	....	12	....	14	....	0	....	0	....	0	....	0
Total number of sacks examined on different days of exposure			8	....	2	....	5	....	4	....	6	....	3	....	6	....
Total number of sacks in which typhoid was found			....	7	....	2	....	3	....	0	....	0	....	0	....	0

[a] Control sack.

[b] At end of 1 hour.

TABLE 81.—*Results of longevity experiments with typhoid bacilli in water of Illinois River at Peoria by the impermeable-cell method*—Continued.

No. of laboratory sack.	Strain of culture used.	Number of typhoid organisms per cubic centimeter inoculated.	9th day.		10th day.		12th day.		14th day.		16th day.		17th day.		Total.
			Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	Number of colonies fished.	Number of typhoid colonies.	
1	X	1,000	....	....	10	0	....	....	....	....	....	....	....	....	.....
2	X	2,000	....	....	....	....	....	....	....	....	....	....	....	....	.....
3	X	4,000	....	....	....	....	....	....	....	....	....	....	....	....	.....
4	X	10,000	....	....	....	....	....	....	....	....	....	....	....	....	.....
5	X	20,000	....	....	12	0	12	0	11	0	....	....	15	0	.....
6	Y	1,000	....	....	....	....	....	....	9	0	....	....	....	....	.....
7	Y	2,000	....	....	....	....	5	0	5	0	6	0	....	....	.....
8	Y	4,000	....	....	6	0	4	0	....	....	8	0	....	....	.....
9	Y	10,000	....	....	11	....	....	....	....	....	....	....	....	....	.....
10	Y	20,000	....	....	7	0	6	0	....	....	....	....	....	....	.....
11[a]			....	....	....	....	....	....	....	....	....	....	....	....	.....
12	Z	540	....	....	....	....	2	0	....	....	....	....	....	....	.....
13	Z	540	4	0	....	....	7	0	....	....	....	....	....	....	.....
14	Z	5,400	....	....	....	....	....	....	....	....	....	....	....	....	.....
15	Z	10,800	14	1	....	....	2	0	....	....	....	....	....	....	.....
Number of colonies daily examined from all sacks			18	....	46	....	38	....	25	....	14	....	15	....	459
Number of typhoid colonies found on successive days			....	1	....	0	....	0	....	0	....	0	....	0	70
Total number of sacks examined on different days of exposure			2	....	5	....	7	....	3	....	2	....	1	....	54
Total number of sacks in which typhoid was found			....	1	....	0	....	0	....	0	....	0	....	0	14

The witness then described another experiment, as follows:

Nonnutrient agar from which all soluble products had been removed by washing was prepared in rectangular blocks about one-half inch square and 2 inches long. These blocks were inoculated in the center with freshly grown typhoid cultures forced into them by a platinum wire. After removing the wire the point of entry was sealed from contamination by searing the surface with a hot iron. According to Oswald, such agar possesses the property of allowing diffusion to take place quite as rapidly through its substance as through water. Hence it follows that typhoid organisms inclosed in the interior of such an agar mass, if exposed in an aqueous medium containing bacteria of various kinds, would be subjected to the same influences arising from the growth and development of water and of sewage bacteria as they would if they were placed directly in the water, but with the difference that the typhoid organism would not come into actual contact with extraneous water and sewage organisms. These blocks, inoculated with the three strains of typhoid bacilli mentioned in the testimony of Professor Jordan and designated as *x*, *y*, and *z*, were placed in the waters of Illinois River in small galvanized-iron cylinders, the top and bottom of which were covered with coarse wire netting.

Under these conditions the water had free access to the individual blocks. The results were as follows:

Series 1, inoculated with culture *x*, was examined on the first day by taking one of these agar blocks and tearing off the upper surface and attemping to transfer any material which was in the line of the inoculation previously made. Similar transfers were made on the third, fifth, ninth, twelfth, fourteenth, sixteenth, and seventeenth days after immersion. In no case did any growth occur on these subcultures.

Series 2 was inoculated with the same organism and subcultures were made immediately and on the first, second, third, sixth, eighth, tenth, and thirteenth days. Growth was produced from the cultures made immediately and on the second day.

Inoculation of series 3 was with the *y* strain and tests were made immediately after inoculation and on the first, third, fifth, seventh, tenth, twelfth, fourteenth, and seventeenth days. In no case were positive subcultures transferred except immediately after inoculation and on the fifth day.

The fourth series was inoculated with the *z* strain and subcultures were transferred immediately and on the first, second, third, sixth, eighth, tenth, and thirteenth days. No positive results were found except in the transfers made immediately after inoculation and on the first day.

The above experiments were conducted in the waters of Illinois River at Peoria. Subsequently two experiments were made in the waters of Lake Mendota at Madison, Wis., where cultures were removed on the third, seventh, tenth, eleventh, twelfth, fifteenth and twenty-first days after immersion, but the typhoid-fever organism was isolated only in the samples removed on the third and seventh days. The experiments as a whole showed a variation in the vitality of the typhoid organisms and a rapid destruction of them when exposed, not to the water nor the extraneous bacteria themselves, but merely to the soluble products which these germs are capable of producing. Control experiments were instituted with these agar blocks inoculated with the typhoid bacilli, the blocks not being exposed in the water but kept in the air. The results showed that the organism was capable of retaining its vitality for at least two weeks, and on some occasions for a longer period. (6516–6519.)

The witness stated that from the results of his experiments, taken together with those of Professors Jordan and Zeit, he would conclude that the typhoid organism would live when immersed in the waters of Lake Michigan for a period of six or eight days, in Chicago River from two to three days, and in Illinois River from three to four days at the longest. In view of the results obtained by the experiments, and the fact that in the judgment of the witness typhoid organisms deposited

in Chicago River, the drainage canal, and Illinois River would be subjected to influences even more detrimental than those existing under the conditions of the experiments, he was of the opinion that it would take a much longer period of time for the Chicago sewage to pass down Desplaines and Illinois rivers and finally reach Chain of Rocks than is required to kill typhoid organisms when placed in such an environment as that existing along these watercourses. The conditions under which the experiments were made approach more nearly the actual conditions to which the typhoid-fever organism is subjected when exposed in a flowing river, and therefore from a scientific standpoint a greater value may be attached to conclusions based on these experiments than to any conclusions that had been previously drawn from the experiments of other investigators. The results show that typhoid bacilli live longer in pure water than in polluted water. The experiments also shed light on the longevity of typhoid bacilli in the sediment of polluted streams. Under such conditions the pathogenic bacteria are brought into contact with even a larger number of other organisms than when they are exposed in the waters of a river, and therefore they are presumably in contact with increased amounts of unfavorable metabolic products, so that such conditions are certainly not less prejudicial than those found in the water of the stream itself. The witness expressed the opinion that if the longevity of the typhoid bacillus is impaired by the action of sewage and of water bacteria in a polluted stream, at least the same if not a greater effect would be produced if such typhoid organisms were in contact with these bacteria and the products of their growth in the sediment of the stream. (6519-6523.)

The witness differentiated between the conditions prevailing in moist soil and in the sediment of running streams as follows:

In the case of moist soil the interstices between the particles are not entirely filled with water, but a considerable amount of these spaces is filled with air. In the sediment found in running streams or lakes such interstices are entirely filled with water. Under the latter conditions the unfavorable products of the growth of bacteria would be greatly diffused among the typhoid bacilli deposited there, while under the former conditions such ready diffusion could not take place, and therefore the typhoid bacteria would acquire a longer lease of life. Therefore, observations of the longevity of the typhoid germ in moist soil are not reliable bases to determine its longevity in stream sediment. The conditions are not comparable. (6525-6530.)

With reference to the evidence cited by George W. Fuller concerning the persistence of typhoid germs in the sediment of Lake Geneva, the witness, after reviewing the conditions, stated that the results were doubtful, because early findings with reference to the discovery of the typhoid organism must be regarded as more or less unreliable,

for the reason that no bacteriological data were given concerni technical methods employed, and therefore the conclusions pre are not justified from an experimental point of view. (6530-6

The attention of the witness was then directed to the typho tistics of St. Louis and Chicago and the general drainage a Mississippi and Missouri rivers above St. Louis. He cited t methods of interpreting statistics known as the mortality per and the rate per unit of population methods, and expressed a ence for the latter, for the reason that in his opinion the fo liable to introduce errors which might readily vitiate the acc the statistics. When the number of deaths from any pa disease is compared with the total number of deaths, a wro of comparison is involved. What is wanted in any given com is to know whether a disease is increasing more rapidly t increase in population. The fatality rate of any disease sh be based on the ratio between the death rate from that dis the total death rate, because the variation which often occu total death rate may be subject to many conditions. Supp example, that a serious epidemic of some disease like bubon or yellow fever should occur. It would be manifestly imp compare the typhoid death rate in that community with t number of deaths because in such case it would be shown typhoid rate was decreasing; whereas it might actually b increase, but by reason of the unusual number of deaths du epidemic of the other disease it would appear to be less by son. (6540-6542.)

The witness then expressed the opinion that the liability of epidemics arising by infection from rural populations w underestimated and cited a number of well-known cases— those at Lausanne, Switzerland; Plymouth and Butler, Pa.; Mass., and Ithaca, N. Y.—all of which were attributed to points of infection in rural communities. Such infection is e to be feared on account of the carelessness which prevails communities in the disposition of the dejecta. Disinfectio maintained as faithfully in the country as in cities. (6542-

The witness then gave it as his opinion that the eviden adduced from the chemical and bacteriological studies of rive affords the best possible means known to determine whet waters are likely to serve as carriers of infection. The a evidence that can be gathered from samples of such waters frequent intervals for a considerable period of time should s progress of self-purification in such running streams, and t furnished become the foundation on which a sanitarian or ep ogist must base his conclusions, although it has been abu

proved that water supplies are not the only means by which typhoid epidemics may be disseminated. (6543–6545.)

With reference to the apparent increase of typhoid fever in St. Louis during 1900 to 1903, inclusive, as compared with previous years, the witness stated that, assuming that these statistics are true and taking into consideration the conditions which prevailed in the drainage basins of the three rivers mentioned and the fact that there are sources of pollution from which typhoid organisms might arise which are not so far removed from St. Louis as Chicago, and taking into consideration further the results of typhoid experiments which have been made, as detailed in the testimony, he thought that there was no scientific reason justifying the conclusion that the increase reported by the St. Louis board of health for the period above mentioned is due to infectious matter derived from the sewers of Chicago by way of the drainage canal. (6545–6546.)

The terms remittent, intermittent, typho-malarial, congestive, and simple continued fevers are relics of old methods of description which attempted to differentiate these febrile changes merely on the basis of the symptoms most evident. They are not recognized by bacteriologists or clinicians of the present time as being satisfactory names for specific types of fevers. The witness was then asked a hypothetical question, based on the assumption that the number of deaths reported as occurring from typhoid fever and from remittent, intermittent, typho-malarial, congestive, and simple continued fevers during the period from 1890 to 1903 in St. Louis was as shown in Table 80 (p. 242). In reply he expressed the opinion that the record for typhoid fever did not represent the total number of deaths from that disease occurring in the city, and that the large number of deaths reported from the remittent fevers was due to improper diagnosis. If the deaths attributed to the other diseases had been diagnosed according to modern methods they would in the large majority of cases have been found to be typhoid fever, and it was the opinion of the witness that they should all be included in the statistics as such. The death rate from the malarial fevers indicated in the second column is comparatively insignificant in the United States, and of necessity it follows that no city has so high a death rate from these diseases as is represented in the number of deaths reported in the St. Louis statistics. It would be practically impossible for anyone to give an accurate idea as to what percentage of the deaths reported as due to those diseases should be certainly charged to typhoid fever, but it would undoubtedly be safe to attribute a large proportion to this disease. It is noteworthy that in regions where malaria is known to be common, and where the best modern methods of diagnosis are employed, the large number of deaths reported as due to genuine

malarial fever has been greatly reduced since the introduction of those methods. (6549–6556.)

Taking into consideration the fact that the typhoid statistics as reported to the health commissioner of St. Louis did not represent the actual conditions in that city with reference to the disease, but that these statistics should be increased by a large proportion, if not all, of the deaths reported under the captions remittent, intermittent, typho-malarial, congestive, and simple continued fevers, the witness expressed the opinion that when such additions are made for the period covered by the statistics presented, and when the corrected statistics are compared with the typhoid-fatality statistics of other cities where similar types of water supply are used for municipal purposes, they show that there had been no increase in the actual number of typhoid deaths occurring in St. Louis from 1900 to 1903, inclusive, as compared with the rate prevailing for the period 1890 to 1900, inclusive. (6559–6560.)

The water supply of St. Louis is not less valuable for drinking purposes nor more liable to carry water-borne diseases since the opening of the Chicago drainage canal than it was before, because experiments have shown that the typhoid organism is killed in Illinois River in a period of time less than that which is necessary for the water to flow from Chicago to St. Louis; and, the destruction of typhoid organisms being assumed as an index of the destruction of all pathogenic organisms in water, it is safe to assert that the same statements are true for the cholera germ. (6560–6561.)

The increase in the speed of the current of Illinois River caused by the added volume of water discharged into it from the drainage canal probably alters the manner of sedimentation occurring in the river. The added water carries with it a larger amount of suspended organic matter and therefore increases the amount of suspended material, the result being an increase of sedimentation. If this increase did not cause an overflow of the banks, the speed of the current would carry the suspended matter farther downstream, but it was the opinion of the witness that the removal from the river of the sewage from Joliet, Peoria, and other places along the banks would be effected before such sewage reaches the Mississippi, so that it would not materially alter the condition of the Mississippi, except in the case of such salts as chlorides and nitrates, which are not eliminated from the water in the purification of sewage. In case, however, the water is made less turbid by the addition of the discharge of the Chicago drainage canal the sedimentation that would normally occur in the river would be lessened. From the experimental evidence previously adduced concerning the limited period of life of the typhoid organisms it would follow that an additional volume of water discharged from the drainage canal, causing an increase in the speed of the current of Illinoi

River, would not have any effect in increasing or diminishing typhoid fever among the inhabitants of the State of Missouri who use the waters of the Mississippi below the mouth of Illinois River. (6561–6562.)

The witness then contradicted the assertion of Professor Sedgwick concerning the longevity of the germ of typhoid fever, namely, "My belief is that in a sewage-polluted stream the typhoid germ might live in gradually diminishing numbers for weeks, or months, or even years," stating that it has been shown by experimental evidence that the typhoid organism dies out with special rapidity in sewage-polluted waters. He also considered untenable the assumption of Professor Sedgwick that typhoid fever germs could pass from the sewers of Chicago by way of the drainage canal to Lake Peoria and be deposited there in the bed of the lake for a period of one month and afterwards be swept out and contaminate the water supply of St. Louis. He further stated that he knew of no evidence justifying Professor Sedgwick's conclusion that there might at times be a larger number of typhoid organisms in Lake Peoria, due to accumulations there, than would actually be passing out of the drainage canal at the Bear Trap dam. On the contrary, there was every reason to believe that the typhoid organisms present at the Bear Trap dam would be entirely discharged before reaching Lake Peoria. (6562–6566.)

The witness expressed the opinion that the five dams erected across Illinois River would act in a material way in aiding the sedimentation of dangerous matters deposited in that stream, but in view of the fact that the sewage of Chicago is practically purified before it reaches these dams they actually have no effect on purification of the river so far as Chicago sewage is concerned. (6577–6578.)

Missouri River, draining a large area on which many cities are located which discharge sewage into the stream, must be regarded as very liable to carry pollution for varying distances, and therefore can not be considered as a safe source of water for drinking purposes at Fort Bellefontaine. Illinois River above Grafton was also considered unsafe, but the opening of the drainage canal did not make it more unsafe than it was previous to the date of the opening. The witness then closed his direct testimony with the following statement:

In view of the fact that the conditions which obtain in the city of St. Louis and the conditions of the watersheds which are immediately adjacent to this city; in view of the fact that the typhoid-fever death rate in that city is dependent upon other conditions than those due to the water supply of that city and may be materially influenced by operation of many other factors; in view of the conditions which obtain in the Illinois River with reference to the process of purification which would occur in the sewage of Chicago when deposited in the drainage canal; and taking into consideration all the knowledge which I possess with reference to all data which bear directly or indirectly upon the question involved, it is my opinion that the increase

in the typhoid deaths, as reported in the city of St. Louis, assuming such increa be true, which have occurred since the opening of the drainage canal, can not be all reasonable doubt be attributed as a direct, immediate, and approximate cau said increase to the opening of that drainage canal. (6581.)

CROSS-EXAMINATION.

With regard to the index of sewage pollution in surface waters witness stated that it is generally conceded that the presen bacteria belonging to the colon type is significant. A water s containing a large number of these organisms can be regard bacteriologists as having been more or less polluted with sewa no distant date. He did not recall any cases where under m conditions a water had been infected with disease-producing o isms to such an extent as to be able to produce epidemic diseas where such water had failed to reveal the presence of the organisms in considerable numbers, although he could concei cases in which infection was sporadic and discontinuous, wher evidence of such infection might not be revealed by bacteriol examination and still that water may have previously been the of an epidemic of disease. (6583–6584.)

Bacteria of the colon type might be found in water that had unexposed to sewage. The colon organism is a normal inhal of the intestinal tract of higher animals and therefore its mere ence in a surface water can not be regarded as direct evider human pollution; but the intimate relation existing between ogenic organisms capable of producing disease and certain known bacteria which do not belong to the distinctive path class, but which are always present in intestinal discharges, ma advisable and necessary to resort to the colon test. (6585.)

E. G. HASTINGS.

E. G. Hastings, called as a witness on behalf of the defen stated that he was an instructor in bacteriology. His testi was a corroboration of that of H. L. Russell with reference t experiments on the longevity of the typhoid baccillus when exp to sewage. The witness was Professor Russell's assistant in co tion with the experiments on parchment cells and made inocula therefrom in the work carried on in Illinois River at Avery (6716–6733.)

F. ROBERT ZEIT.

DIRECT EXAMINATION.

F. Robert Zeit, a witness called in behalf of the defendants, stated that he was a teacher in the Northwestern University medical school and post graduate medical school of pathology and bacteriology, having occupied the position for five years; he had received his early education in Switzerland and Germany, and had taken the regular medical course at the Western Reserve University at Cleveland, Ohio, from 1884 to 1887; afterwards for three years he was instructor and collaborator in the private laboratory of Professor Klebs, instructor of pathology in the Rush Medical College; he was then called to the Northwestern University as teacher in bacteriology; after one year was made professor of bacteriology in the university medical school, and later was placed in charge of the entire department of pathology and bacteriology. During the entire seven years in which the witness was engaged exclusively in teaching bacteriology and pathology he had made special studies of these questions. Before engaging in the profession of teaching, he had practiced medicine and surgery in Wisconsin and in Chicago for ten years. (4396–4398.)

The witness stated that from February 6 to October 1, 1900, he had made bacteriological examinations of the waters of the Chicago drainage canal and Illinois River, samples being furnished to him by Professor Long. He stated that in this series of investigations his province had been merely the determination of the presence or the absence of pathogenic bacteria. He did not make any counts of colonies or any of the usual tests. The samples when received from Professor Long were plated out on gelatine and agar; from three to sixteen dilutions were made in Petri dishes. Glucose agar plates for the growth of anaerobes were also made. All the gelatine plates were kept at a temperature of 20° to 22° C. and the agar plates in the incubator at 37° C. The plates were examined daily and pure cultures obtained on agar from the various colonies, between the second and eleventh days. The pure cultures were then subjected to such further study as was necessary. The results of the examinations are set forth in Table 82. (4398–4421.)

TABLE 82.—*Results of bacteriological examinations of waters of the drainage canal and Illinois River, taken from designated points, 1900.*

	Lake Michigan, tap water.	Drainage canal at Western avenue.	Illinois River at Bridgeport.	Illinois River at Lockport.	Illinois River at Joliet.	Kankakee River at Wilmington.	Illinois River at Morris.	Illinois River at Ottawa.	Fox River at Ottawa.	Illinois River at La Salle.	Illinois River at Henry.	Illinois River at Averyville.	Illinois River at Peoria.	Illinois River at Havana.	Spoon River at Havana.	Illinois River at Pearl.	Illinois River at Grafton.
Number of samples examined	7	13	7	7	6	2	10	5	4	6	5	5	11	12	8	10	10
PATHOGENIC BACTERIA.																	
Bacillus anthracis														2			
B. coli communis	3	9	6	4	3		6	2	1	2	2	1	8	3	1	1	2
B. enteritidis		3	2	1	2					2							
B. lactis aerogenes	1	4	4	2									2	1			
B. pyogenes			2														
B. tetani							1				1				1		
Micrococcus rhizopodiformis	1																
Proteus mirabilis				1			1							1			
P. vulgaris		6	6	2	3		4	1		3	1		5	1	2	1	2
Staphylococcus pyogenes aureus											1			2			1
NONPATHOGENIC BACTERIA.																	
Bacillus acidi lactici		2	2	2									3	1		1	2
B. aerogenes			1														
B. albus putidus		1															
B. aquatilis	2	3	1	1		1	3		3	2	2		2	1	3	4	2
B. aquatilis sulcatus				1												2	
B. aquatilis sulcatus I		3	1		1				1	3	1			2			
B. aurantiacus																1	1
B. circulans													1				
B. cloacæ				1	2		1	1		1	1		2	3			
B. cloacæ Jordan		3															
B. cyanogens			1		1												
B. delicatulus Jordan		1															
B. flavescens Pohl	1																
B. flavocoriaceus									1							1	
B. fluorescens liquefaciens	1		2		1								2	1			2
B. fulvus					1			1		1							
B. liquidus	2		1						3			1					3
B. liquefaciens								1									
B. megaterium							2			2	1		3	3	2	3	
B. mesentericus	3	2	1		1	1		1			4	1	2	2	3	1	
B. mucormucedo				1	1												
B. mycoides	1	2	1	1	3	1	4		1	3			2	3	1	5	2
B. ochraceus										1							

B. plicatus			1	1	2	1	2		1	4			2	2		
B. reticularis	1												2			
B. reticularis Jordan		1														
B. rubidus			1	1	1					1					1	1	
B. rubifaciens											1			1		
B. striatus flavus											1					
B. subflavus										1	2					1
B. subtilis	4	3	2	1	1	1	3	1			1		5	5	4	3	5
B. superficialis			2		2												
B. ubiquitus				2									2				
B. ubiquitus Jordan		1															
Diplococcus citreus									1								
D. roseus								1	1								1
Micrococcus aerogenes					2			1									
M. agilis		1															
M. albicans										1							
M. aquatilis	2				2								4		1	1	1
M. candicans		3	2	2			2	1								1	
M. citreus												1					
M. flavus desidens			2														
M. flavus liquefaciens	1			1													
M. luteus				1	1								1		2		1
Oidium lactis				1						1							
Orange-red water bacteria				1					1								
Pink yeast								1		1		1					
Saccharomyces cerevisiæ					1							1					
Sarcina aurantiaca				1								1					
S. lutea		2		2	3		1		1	2						1	2
S. rosea	1						1				1	1				1	
Vibrio aquatilis										1							
V. aqatilis Gunther	2	1															
V. aureus	1																
V. flavus								1									
Yellow water bacillus		1															
Yellow water bacillus (Lustig)												1					

The witness stated that in connection with the foregoing investigations experiments were made on guinea pigs by injecting in each 4 c. c. of water from each of the stations where samples were procured. Another set of experiments was made in the same manner with cultures obtained from the samples submitted by adding 1 c. c. of the water to 5 c. c. of nutrient bouillon and keeping the mixture in an incubator at a temperature of 37° C. for twenty-four hours. The guinea pigs inoculated with the specimens of the Lake Michigan tap water all recovered, and of three guinea pigs inoculated by intraperitoneal injections with cultures obtained from this water only one died of sepsis, and subcutaneous injections caused only local abscesses, from which the animals all recovered. Intraperitoneal injection of the guinea pigs with water taken from the drainage canal at Western avenue did not prove fatal in any instance, but the animals injected with cultures invariably died. Injection of the water obtained at Bridgeport did not produce death, but all the cultures were fatal, though in only one instance did death result from subcutaneous injection. Water taken at Lockport produced no results, while the effect on animals inoculated with cultures from these samples was varied—some of them recovered, one died of sepsis, and one that had apparently recovered died after a period of about two weeks, though post-mortem examination failed to disclose bacteria. In the blood of the animal which died promptly proteus forms were most prominent. All those which recovered had an elevated temperature and lost rapidly in weight for several days. Water taken at Joliet when injected intraperitoneally produced no effect, and of all the animals inoculated with cultures only one died of sepsis, the others recovering. Both the water and cultures taken at Wilmington, on Kankakee River, produced no results by intraperitoneal injection. Direct intraperitoneal injection of the water taken at Morris, on Illinois River, in one instance caused death in eleven days, while other samples did not produce fatal results. Experiments with mixed cultures gave uncertain results, some of the animals dying and some not. Samples of water taken from Illinois River at Ottawa and cultures obtained therefrom proved not to be virulent. Samples from Fox River at Ottawa and mixed cultures obtained from them were nonproductive of fatal results. Illinois River water taken at La Salle in one case proved fatal, the animal dying of sepsis. The cultures of this water, however, were very virulent. Direct injection of the water taken at Henry did not cause death, though the mixed cultures from these samples were virulent. The cultures obtained from Averyville samples were entirely nonvirulent. The witness stated that the evidence of bacterial self-purification afforded by the examination of these samples showed that there was a gradual decrease in the number of disease-

producing as well as sewage bacteria from Chicago to Averyville. He believed that the experiments on the guinea pigs constituted sufficient proof that the zone of self-purification must be reached somewhere above or near that place. With regard to the samples received from Peoria, he testified that direct injection of the water caused death in eleven days, while another animal died of sepsis within twenty-four hours after inoculation, and that the bacteria markedly increased at this point. Both the water taken from Illinois River at Havana and the cultures made with it were shown to be highly productive of disease in guinea pigs and white mice when injected intraperitoneally. A number of the animals died of anthrax bacteremia within forty to forty-eight hours, and the blood of all of them contained numerous anthrax bacilli. Water taken from Spoon River at Havana, however, did not prove fatal in any instance, nor were the cultures virulent. Samples taken at Pearl and Grafton and the cultures obtained therefrom were nonvirulent. (4403–4421.)

With reference to the relative longevity of disease-producing organisms and the ordinary water bacteria and saprophytes in Illinois River and the drainage canal, the witness stated that the growth and multiplication of the ordinary water bacteria depend very little on organic matter in the water or its temperature, but the condition and growth of the saprophytic or sewage bacteria are largely governed by the presence or absence of dead organic matter, and they usually require a somewhat higher temperature than the ordinary water bacteria. The existence or disappearance of the pathogenic or disease-producing bacteria (including the typhoid and cholera bacilli) is dependent on dilution, light, temperature, and the presence or absence of large numbers of saprophytes. Where the saprophytes are numerous, the typhoid and similar pathogenic bacteria are rapidly overgrown by them and disappear in five or six days. Where conditions are favorable to the production and multiplication of water bacteria, the existence of the pathogenic bacteria reaches eight to ten days. If typhoid bacilli, however, are placed in water containing none of the other two types of bacteria, they can live for weeks, even in the absence of food. The higher the temperature the more favorable the conditions are for the growth of the disease-producing bacteria, while low temperatures make their multiplication impossible. According to the witness the typhoid bacilli, in the absence of many water bacteria and saprophytes, will live for some time; the smaller the number of saprophytes the longer the existence of the typhoid bacilli. (4421–4422.)

The witness further stated that the typhoid bacillus will multiply only in a favorable temperature, the optimum being 37° C., or about blood heat, and only where there is organic matter for food. While the typhoid bacillus can grow in as low a temperature as 24° C., a

mixture with other rapidly growing bacteria at this temperature will result in its overgrowth and disappearance. (4423.)

He then expressed the opinion that the number of bacteria is not of so much importance in determining the purity or impurity of a given body of water as their character. The number of water bacteria may be very great and not have much significance, whereas if they are sewage or pathogenic bacteria the number may be very small and the water might be called perfect chemically, but could not be called perfect bacteriologically. Furthermore, to judge solely by the number of bacteria present, a water containing less than 50 germs per cubic centimeter would have to be called a good water, and yet if these 50 germs happened to be disease producing the water should be condemned. The number of bacteria is significant only in determining, after the normal condition has been ascertained, whether pollution in a given body of water is increasing or diminishing. The essential point is the quality of the germs and whether they are sewage or water bacteria. (4426.)

The witness stated that he had not found any typhoid bacilli in his examinations of the waters of Illinois River or the drainage canal, but that this was by no means strange, because it was frequently the case that sewage contaminated with typhoid bacilli got into comparatively large bodies of water where the dilution would be so tremendous as to make it difficult or impossible to relocate the germs. The typhoid bacillus does not multiply at the normal temperature of river or lake water, and in case of contamination of such waters by sewage the typhoid germs are overgrown by water bacteria and ultimately disappear. The witness stated that even where it is known that a water supply has been contaminated by sewage containing typhoid bacilli, bacteriologists have been unable to find these germs, the reasons being, first, that the unfavorable temperature of the water prevents multiplication of pathogenic organisms; second, that sewage bacteria undergo rapid multiplication and overgrow the parasitic bacteria; and, third, that extensive dilution takes place and separates the bacilli so far that they can not be found. Furthermore, in most epidemics where search has been made for typhoid bacilli and they have not been found, the time of infection or of contamination has no doubt been passed by several weeks, and the typhoid bacilli which might have been found earlier have entirely disappeared during that period. (4427.)

Being asked what significance was to be attached to the gradual disappearance of sewage and pathogenic bacteria in running water, the witness expressed it as his opinion that by reason of the overgrowth of saprophytes in the presence of organic material, together with a temperature favorable to their rapid multiplication, the pathogenic bacteria in such water are destroyed entirely. In other words,

by the rapid multiplication of sewage bacteria, the disease-producing bacteria, which grow best at the temperature of the body, will be overgrown and will perish, so that by the time the sewage bacteria and organic matter has disappeared the purification of the water of pathogenic bacteria must be complete. (4431.)

Assuming that the dejecta of typhoid-fever patients in Chicago are carried into the drainage canal through the sewers of the city; that the waters in that canal contain immense numbers of saprophytes and ordinary water bacteria, to the number of 70,000 and frequently as many as 4,000,000 per cubic centimeter; that it requires at least twenty-four hours, and at times as much as forty-eight hours, for the water to pass from the Chicago sewers into Chicago River and the drainage canal and reach the Bear Trap dam; and assuming further, that the flow in Desplaines and Illinois rivers is equal to 40 miles in twenty-four hours, the witness expressed the opinion that the typhoid bacilli would not survive as far as Peoria, for the reason that the saprophytic bacteria increase at such a tremendous rate in the drainage canal as to actually overgrow and annihilate any pathogenic bacteria in the water. (4456–4458.)

With reference to the conclusions to be drawn from his experiments, set forth in Table 77, as to the relative bacterial purity of the respective streams at the time of examination, the witness stated that he would regard Missouri River as more polluted than the Mississippi or the Illinois, and the Mississippi as more polluted than the Illinois. (4459.)

The relative longevity of the typhoid bacillus as compared with that of *Bacillus prodigiosus* was stated by the witness to be ordinarily very similar, though it depends entirely on the surrounding conditions. It was his opinion that in the waters of Illinois River and the Illinois and Michigan Canal *Bacillus prodigiosus* would live longer than the typhoid bacillus. (4463–4464.)

The witness stated that in his examinations of the waters of Lake Michigan, Chicago River, Illinois River, and the drainage canal he had never discovered *Bacillus prodigiosus*, but that he had, during the early part of his work in 1900, occasionally obtained in Lake Michigan a few red colonies which appeared to have all the characteristics of this germ, differing, however, in that they grew very well on sterilized banana slices, were larger than the ordinary *B. prodigiosus*, and occasionally produced gas. No description of another organism could be found in literature corresponding to these bacteria, and so he had been inclined to call them *B. prodigiosus*, but while on culture media they seemed almost identical with *B. prodigiosus*, on agar they had the appearance of red sealing wax. For this reason he had called them the sealing-wax organisms. (4465.)

The zone of bacterial purification of a river, according to the witness,

is that part of a sewage-polluted stream where saprophytic organisms and pathogenic bacteria have disappeared and where the normal bacterial flora of the river before it received the pollution is again established. This zone varies in different rivers and in different localities between distances of 9 to 40 miles. As examples of rivers in which the zone of purification has been determined by bacteriologists, the witness cited the following:

The River Seine, after receiving all the sewage of Paris, purifies itself within a distance of 70 kilometers, or 43 miles, having the same number of organisms and the same bacterial flora that it had before receiving the sewage.[a] The River Oder receives the sewage of Breslau and 20 miles below the city contains the same number of bacteria that it did previous to receiving the sewage.[b] The city of Zurich, Switzerland, discharges its sewage into the River Limmat, which flows from a lake of very pure water, containing between 100 and 200 bacteria per cubic centimeter. Fourteen kilometers, or 9 miles below the city, this river has again established its bacterial purity.[c] The River Isar receives all the sewage of Munich and purifies itself within a distance of 33 kilometers, or 20 miles.[d] The River Spree, after receiving the sewage of Berlin, which is so great as to cause the bacteria to increase to about 1,000,000 per cubic centimeter, flows through the small lake of Havel, and on its exit from the lake at Sacrow has practically the same bacterial condition that it had previous to receiving the Berlin sewage[e]. The distance traveled by the sewage-polluted water was believed by the witness to be about 9 miles. (4466–4468.)

The witness expressed the opinion that typhoid bacilli, after lying in the bed of a stream for a period in excess of sixty days, would be unable to cause typhoid fever when taken into the human system, and when asked if a substance coming from the sewers of Chicago through the drainage canal and deposited on the bed of Illinois River could remain for any considerable length of time and still retain its dangerous qualities and pathogenic bacteria, he stated that he believed such pathogenic bacteria would die in the drainage canal, owing to the increase of saprophytic bacteria. It was his opinion that the sewage discharged by Chicago into the drainage canal could not and did not constitute a menace to St. Louis or to the inhabitants of Missouri. From all the examinations he had made of Illinois, Mississippi, and Missouri rivers during October, November, and December, 1901, and February and March, 1902, it was his opinion that bacteriologically the Illinois was less polluted than either of the other two rivers. (4471–4473.)

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[a] Rubner, Hygiene, Berlin, 1901.
[b] Frankland
[c] Schlatter, Zeitschrift für Hygiene, vol. 190, p. 56.
[d] Prausnitz, Hygiene, 1900 or 1901.
[e] Zeitschrift für Hygiene, vol. 3 ,p. 355.

With reference to the *Bacillus prodigiosus* experiment described in the testimony of Doctor Ravold, for the complainant, the witness stated that there should be considerable doubt as to the identity of the few *prodigiosus* bacilli reported to have been discovered after the discharge of the cultures into the drainage canal, for the reason that the isolation of these bacteria was based on the red reaction test alone, which is not sufficient to establish their identity beyond question. Therefore, taking into consideration the many millions of these bacilli discharged into the canal, their practical absence afterwards would be an indication of the purification of the water; and since the typhoid bacillus would not live as long under these same conditions as *B. prodigiosus*, it would follow that typhoid bacilli discharged into the drainage canal from the sewers of Chicago would not survive the passage down Illinois and Mississippi rivers and into the intake tower of the St. Louis waterworks at Chain of Rocks. (4477–4478.)

CROSS-EXAMINATION.

During the cross-examination the witness stated that he had made experiments on the life of the typhoid germ in samples of water from Illinois River at Grafton, Missouri River above its mouth, and Mississippi River above its confluence with the Illinois. The river water was first inoculated with different known quantities of twenty-four-hour bouillon culture of typhoid bacilli and placed in the refrigerator at a temperature of 10° to 12° C. It was then plated out daily on agar in a number of dilutions. Fifteen to twenty plates were made, and from these the one showing the most distinct colonies was selected and all the colonies thereon that looked like typhoid were marked for examination. It was then determined whether or not the colony was a bacillus and if so whether or not it was motile. If not a motile bacillus, it was thrown out. The Widal reaction would be obtained with a motile bacillus by the use of the serum of an immunized rabbit or the blood of a typhoid patient. A positive reaction was considered satisfactory evidence of the presence of the typhoid bacillus, but where no such reaction could be obtained the usual cultures were made of the suspicious motile bacilli. In these experiments, the witness was unable to find the typhoid bacillus after five or six days, even where large quantitles of bouillon culture were inoculated into the water. (4482–4483.)

The witness stated that when the water of a river was at the freezing point, as it is in the coldest part of the year, both saprophytes and typhoid bacilli would probably remain as they would in ice; that as the temperature became lower than that of the air the saprophytes would increase less and less, and that, in his opinion, conditions in water polluted by sewage are more favorable for the life of the typhoid

bacillus than the conditions would be in laboratory experiments, owing to the greater amount of organic matter present in the polluted water. (4485–4487.)

In comparing the effects of the injection of typhoid and colon bacilli, the witness stated that if typhoid culture is injected into an animal no infection results, but death follows from poisons producing a toxic effect, all animals being immune from typhoid fever. Injection of the colon bacilli may result in death through toxic causes, but injection is usually followed by an infection, the animal dying of septic peritonitis after a period of five to ten days. (4536–4537.)

In response to a direct question the witness admitted that it would be possible for typhoid germs which had been frozen into a block of ice in the drainage canal, on the passage of the ice down the canal and into Illinois River, to reach the intake of the St. Louis waterworks if the bacteria had survived the freezing process. (4609.)

REDIRECT EXAMINATION.

Four months later Professor Zeit was recalled for further direct testimony and stated that since having previously testified in the case he had, in conjunction with Professors Jordan and Russell, made experiments on the longevity of the typhoid bacillus, his part of the work having been the examination of samples of water from Lake Michigan and Chicago River. Two plans were adopted. The first involved the use of parchment sacks and the second the use of celloidin sacks, both intended to allow osmosis and both containing typhoid bacilli in the presence of the saprophytes normally present in the waters, the object being to allow the saprophytic bacteria to multiply and yet not retain within the sack their excretions, which would destroy the typhoid bacilli. There was a free interchange of conditions inside and outside of the sack, the one difference being that within the sack were imprisoned the typhoid bacilli. (6421–6422.)

The sacks were inoculated with typhoid bacilli that had been grown upon agar slants for twenty-four hours in the incubator, enough of the bacilli being placed in the sacks to produce a mixture of about 500,000 typhoid bacilli per cubic centimeter of water. One strain of typhoid bacilli, received from Professor Jordan, was obtained from the blood of a typhoid-fever patient in the Cook County hospital. A second strain, received from Parke, Davis & Co., of Detroit, had been used to immunize a horse. With this strain the serum of the immunized horse was also received. The sacks were suspended in Chicago River at the Ashland Avenue Bridge in boxes similar to those described in the testimony of Professor Jordan, and in Lake Michigan similar sacks were suspended in a jar through which the fresh lake water was constantly flowing. From the time the sacks were sus-

pended in the two localities agar plates from both samples were made daily. (6423–6424.)

In the experiments conducted with the parchment sacks a typhoid suspension, made by distributing material from colonies grown upon agar slants for twenty-four hours, was used. The sacks were first filled with 800 c. c. of river water, to which was then added enough of the suspension of typhoid bacilli to make in the sack a mixture of 200,000 to 1,500,000 typhoid bacilli per cubic centimeter of water. The average mixture used contained 500,000 bacilli per cubic centimeter of water. After infection samples were plated out at once and on the following day a sample of the water was removed from the sack by means of a sterile pipette, the sack having been first examined for leaks. This sample was immediately taken to the laboratory and plated out. For each agar plate from 0.001 to 5 c. c. was used. Eight experiments were made at each of the sampling points, and a number of examinations were made for each experiment, the first being usually twenty-four hours after the placing of the sack in the water and the others daily thereafter. (6424–6425.)

In the parchment-sack experiments only one sack was placed in the water for each experiment, and samples were removed daily for examination, but in those with the celloidin sacks a number of sacks were placed in the water at the same time and one sack was removed each day for the examination. In no case was a sample of water removed from the celloidin sack for examination, the object being to avoid all possible chance of contamination. (6426.)

After the samples of water had been taken to the laboratory and plated out the agar plates were placed in the incubator over night. They were examined from day to day and any suspected typhoid colonies were inoculated into the Hiss medium. The colonies which in the medium proved to be nonmotile bacteria or which produced gas were thrown aside. The motile colonies which showed no gas were then tested with the serum of the immunized horse. In all the experiments it was found that although during the first twenty-four hours the total number of bacteria increased greatly the typhoid bacilli could still be detected. Then a decrease would set in, and in no case were the typhoid bacilli found after a period of three days. The results of the experiments with the two types of sacks were practically the same. The parchment sacks were examined for fifteen to twenty days, while the examination of the celloidin sacks was limited to the number of sacks available, the minimum being eight days. It was found that after two weeks' use the parchment sacks were damaged, and, since in no case were the typhoid bacilli discovered after three days, the conclusion was reached that ten days was sufficient for each experiment, and this was made the limit for future work. (6430–6432.)

Experiments were also made in which the river water was filtered through a Pasteur filter and then plated out to make certain that no water bacteria had passed through the filter. Such raw filtered river water was inoculated with typhoid bacilli and here also it was found that these organisms would not live more than three days. Therefore it appears that there is something in this river water itself which destroys the typhoid bacilli even if they are not subjected to the action of the saprophytes. The witness stated that he brought out this point for the reason that in his former testimony he had made the statement that the disappearance of typhoid bacilli in river water was probably due to the overgrowth of saprophytic bacteria, whereas from these later experiments he had concluded that the river water itself contains some substances, possibly the excretions of saprophytes, which alone are sufficient to destroy the typhoid bacilli within a few days. Experiments were also made by inoculating a typhoid bacillus into boiled river water. In these experiments the bacillus lived three days longer than it did in the raw filtered water. (6432.)

The witness described another experiment in which he added to the water from a parchment sack immune serum from a horse and collected the precipitate in a conical glass tube and added to this precipitate peptone solution, the object being to concentrate the bacteria so that any typhoid bacilli which had escaped detection by the other method might be discovered. Although unsuccessful in this instance, owing no doubt to the fact that all the typhoid bacilli had been discovered by the previous treatment, the witness stated that he considered this a very valuable method in finding the typhoid bacilli, because larger quantities of water can be used. The immune serum agglutinates the bacilli but will not kill them, and they are precipitated and can be grown again on agar plates. (6433.)

The witness said that as a result of the experiments conducted by Professors Jordan and Russell and himself, it was his opinion that typhoid bacilli can not live in the drainage canal, Chicago River, or Illinois River for more than three days, and therefore those discharged from the Chicago sewers can not live to reach the intake of the St. Louis waterworks at Chain of Rocks and thereby constitute a menace to the citizens of St. Louis. (6437.)

During all his examinations the witness had found Illinois River to be less polluted, bacteriologically, than either the Mississippi or the Missouri. Consequently the effect of the addition of the Illinois River water at Grafton would undoubtedly be a tendency to improve the condition of Mississippi River and of the mixture of waters entering the intake tower of the St. Louis waterworks. In conclusion, the witness stated that it was his opinion that the contamination discharged into the drainage canal by the city of Chicago would be

bacterially purified before reaching Averyville and therefore he could not consider it a menace to the health of the citizens of St. Louis. (6441–6442.)

No new facts were brought out on cross-examination.

ROBERT SPURR WESTON.

DIRECT EXAMINATION.

Robert Spurr Weston, a witness called in behalf of the defendants, stated that he graduated at Amherst College in 1891 and for three years thereafter was employed as a chemist in commercial work, after which he became a student at the Massachusetts Institute of Technology and in the University of Berlin; besides this he had been engaged as a volunteer worker in the laboratories of the Massachusetts and the German Imperial boards of health. In 1895 he was connected with experiments on water purification at Louisville and subsequently with similar experiments at West Superior, Wis., and Washington, D. C. In 1900 he was in charge of the water-purification station at New Orleans and conducted an investigation lasting eight months to determine the feasibility of purifying the Mississippi River water. (6869–6870.)

The witness stated that he was well acquainted with the drainage area of Mississippi River above New Orleans, and presented a table showing the distances above that city of cities lying tributary to Mississippi River, as follows:

Distances above New Orleans of cities tributary to Mississippi River.

	Miles.		Miles.
Baton Rouge, La	132	Cincinnati, Ohio	1,415
Natchez, Miss	265	Pittsburg, Pa	1,875
Vicksburg, Miss	366	St. Louis, Mo	1,159
Memphis, Tenn	735	Mouth of Missouri River	1,165
Cairo, Ill	965	St. Paul, Minn	1,823
Louisville, Ky	1,305		

The United States census for 1900 shows that the population in cities and towns containing more than 4,000 inhabitants in Mississippi Valley is about 9,000,000. The witness then presented some data concerning the amount of sewage discharged into the different rivers which make up the drainage area. He assumed that cities which have a population of 25,000 and over will discharge 175 gallons of sewage per capita per day, and that the remainder of the urban population—that is, in cities of 4,000 to 25,000 inhabitants—will produce 100 gallons of sewage per capita per day. This assumption was based on the general water supply. According to a table prepared by John R. Freeman, in a report concerning the water supply of the city of New York, the large cities of the country consume about

100 gallons of water per capita per day, and 75 gallons per day is added for sewage from the streets for ground water flowing into the sewers and for contaminated water from other sources. In smaller cities the daily consumption is approximately 60 gallons per capita, and as a large percentage of these cities are not sewered a correspondingly smaller estimate must be made for the difference between the amount of water consumed and the amount of sewage produced. Taking all the above into consideration, the witness estimated that the amount of sewage from large cities—that is, those above 25,000 population—is 1,174,250,000 gallons per day, and from the remainder of the urban population 342,000,000 gallons per day, making a total of 1,516,250,000 gallons. This amounts to a flow of 2,310 cubic feet per second at New Orleans. The volume of the river at New Orleans being taken into account the maximum dilution is 1 part of sewage to 586 parts of water; the minimum, 1 of sewage to 83 of water, and the average, 1 of sewage to 296 of water. Expressed as cubic feet per second of sewage per thousand of population the maximum is 150, the minimum 21, and the mean 75; and as gallons of water per day per capita of the urban population the maximum is 16,160, the minimum 2,262, and the mean 8,190. (6870–6873.)

The witness then presented Table 83, showing the composition of Mississippi River water at New Orleans from December, 1900, to August, 1901, based on the chemical and bacteriological data. (6877.)

With reference to the figures in Table 83 the witness stated that the analyses, apart from the nitrogen as nitrates and nitrites, show that the water is characteristic of the nonpolluted water for the region. An abundance of oxygen is always present, showing that the organic matter has been decomposed, while the number of bacteria is very low, and they are chiefly associated with the suspended matter. Tests were made for *Bacillus coli communis* during the flood season, that is, from December, 1900, to April, 1901. The volumes used for these tests varied from 1 to 300 c. c., and the bacilli were found only on three occasions during the five months, all during the first week in December. The presence of the organisms at this time only is explained by the fact that on the bank of the river immediately above the intake of the water-purification station where the samples were taken a number of house-boat men and squatters were quartered. The feces deposited by them on the bank during the low-water season were probably washed into the river at the time of high water, and this would account for the presence of *B. coli* in the samples. In all 100 tests were made during the five months, and the general absence of *B. coli communis* leads to the conclusion that no unpurified sewage was present in Mississippi River at New Orleans. (6878–6879.)

	December.	January.	February.	March.	April.	May.	June.	July.	August.
Temperature ..... °C	.....	8.8	8.1	10.8	13.6	19.6	25.0	29.3	29.6
Silica turbidity ..... parts per million	679	187	227	369	630	423	457	515	161
Color	13	11	12	13	14	13	9	11	11
Oxygen consumed ..... parts per million	8.3	4.7	3.5	6.8	11.3	6.9	7.5	7.1	2.9
Nitrogen as—									
Albuminoid ammonia:									
Dissolved ..... do	.104	.063	.056	.054	.077	.060	.045	.055	.046
Suspended ..... do	.228	.088	.140	.196	.358	.185	.195	.167	.032
Total ..... do	.332	.151	.196	.250	.435	.245	.240	.222	.078
Free ammonia ..... do	.017	.017	.013	.013	.005	.006	.004	.005	.005
Nitrites ..... do	.014	.010	.012	.008	.001	.000	.000	.001	.001
Nitrates ..... do	.24	.11	.12	.11	.17	.12	.12	.16	.13
Chlorine ..... do	10.2	9.4	8.5	10.0	7.0	9.3	14.8	8.9	8.3
Incrusting constituents ..... do	19	15	15	11	17	9	11	17	.....
Alkalinity ..... do	67	79	70	84	71	75	82	84	98
Residue on evaporation:									
Dissolved ..... do	142	149	127	146	126	137	157	181	226
Suspended ..... do	549	223	294	425	713	436	469	527	.....
Total ..... do	691	372	421	571	839	573	626	708	327
Iron ..... do	17.0	11.6	14.9	15.6	27.0	12.5	22.6	18.6	10.2
Carbon dioxide:									
Free and half-bound ..... do	.....	58	68	68	51	66	66	47	33
Free ..... do	.....	23	37	31	21	33	32	13	0
Dissolved oxygen ..... do	.....	10.5	10.5	10.0	8.3	7.0	6.0	6.7	5.9
Bacteria per cubic centimeter	2,020	1,315	2,870	1,790	3,590	2,050	2,010	1,835	910

In connection with the above conclusions the witness stated the fact that if the velocity of Mississippi River is assumed to be 4 miles per hour, which is neither the maximum nor the minimum, the sewage from Baton Rouge would reach New Orleans in thirty-three hours, showing the rapidity of disappearance of contaminating matter in the river. He then gave the flow of Mississippi River at New Orleans, taken from the report of the Mississippi River Commission, as follows: Maximum, 1,353,000 cubic feet per second; minimum, 191,000 cubic feet per second; mean, 685,000 cubic feet per second. (6879.)

The witness then presented a chart based on the computation already introduced, showing the relative pollution of Mississippi River at various points, with data for determining it. The evidence contained in this chart is given in Table 84. (6883.)

TABLE 84.—*Relative pollution of Mississippi River water at various points.*

Point.	Mean flow in second-feet.	Population above point.	Dilution in second-feet per 1,000 population.
New Orleans	675,000	9,000,000	75
Mouth of Red River	655,000	8,984,626	73
Mouth of Yazoo River	579,000	8,913,944	65
Mouth of Arkansas River	516,000	8,901,358	58
Mouth of Ohio River	383,000	8,706,902	44

The witness stated that in the above table no allowance had been made for the self-purification of the stream at different points. He then presented a chart showing accessions of sewage to Mississippi River from Cairo to New Orleans. The data of the chart is contained in Table 85. (6887.)

TABLE 85. -*Sewage contributed to Mississippi River, Cairo to New Orleans.*

District.	Mean flow in second-feet.	Urban population of district.	Dilution in second-feet per 1,000 urban population.	Dilution in second-feet per 1,000 sewered.
Below Red River	675,000	15,374	59,900	43,900
Below Yazoo River	655,000	70,682	11,700	9,200
Below Arkansas River	579,000	12,586	4,610	4,610
Below Ohio River	516,000	194,476	2,710	2,650
Above Ohio River	383,000	.....	44	.....

In discussing the information contained in Table 85 the witness stated that the fresh additions of sewage poured into the stream below the mouth of Ohio River are very small in amount. In this table, as in the preceding one, no allowance had been made for self-purification.

The witness then introduced into evidence a chart showing the relative dilution of flow in cubic feet per second of Mississippi River compared with Connecticut and Merrimac rivers. The chart is inserted in the record opposite page 6889. It illustrates diagrammatically the relative dilutions of Mississippi River at Cairo, mouth of

Arkansas River, mouth of Yazoo River, mouth of Red River, New Orleans; of Merrimac River above Lowell, below Lowell, below Lawrence, and below Haverhill; and of Connecticut River above Holyoke, below Holyoke, and below Springfield. The purpose of the diagram was to contrast the two Massachusetts streams with the Mississippi. No allowance had been made for self-purification. The Massachusetts streams receive so much sewage in the form of fresh acquisitions below the points of observation that as the sewage proceeds down the rivers between the limits named it is in constantly greater proportion, while, on the other hand, as sewage is carried down Mississippi River below Cairo it is always in increasing dilution, the fresh acquisitions never being sufficient to maintain the concentration which exists at Cairo. The reasons for this state of affairs are that the Mississippi below Cairo is leveed and the population is relatively small. In the opinion of the witness there is not the slightest evidence that any unpurified sewage exists in the water at New Orleans other than the small amount that might occasionally have been washed in from the banks of the stream outside of the levees. (6889–6890.)

CROSS-EXAMINATION.

On cross-examination the term "unpurified sewage" was defined by the witness as that sewage which has not undergone the cycle of changes which take place when sewage is mixed with an adequate quantity of water in a running stream—in other words, sewage which has not lost its previous bacteriological character. The main effect of dilution is to furnish an adequate amount of oxygen for the oxidation of the organic matter contained in the sewage. This can also be obtained by aerating sewage by passing it over dams, though not in the same degree. The witness was of the opinion that the element of dilution does not have more to do with the small quantities of bacteria contained in the waters of Mississippi River at New Orleans than other bacterial or chemical elements known in sanitary science, because in any other river with which he was acquainted in which the dilution of the sewage approximated the dilution at New Orleans he had been able, by increasing the volume of the samples taken, to demonstrate the presence of *Bacillus coli communis*, but at New Orleans he had been unable to do so. (6890–6892.)

WILLIAM PITT MASON.

DIRECT EXAMINATION.

William Pitt Mason, professor of chemistry in Rensselaer Polytechnic Institute, New York, was called as a witness on behalf of the defendants and stated that he had been connected with the said Institute for over twenty years and had given particular attention

during most of the time to the examination of water for city supplies. This work involved especial study of sanitary problems as related to water supply, and he had written and published books on the subject. He further testified that he had acted in a consulting capacity and testified in legal cases regarding the water supply of many cities and towns in the United States. He had also examined the water supplies of many foreign cities. He was acquainted with the literature bearing on the subject of typhoid-fever epidemics and had made examinations involving study of such epidemics in Bath and Waterville, Me.; Cohoes, Albany, and Buffalo, N. Y.; and other places. He had also made some study of Asiatic cholera in Sicily and Italy. (6903–6906.)

The witness then stated that he had examined and studied the bacterial and chemical analyses of the waters of Lake Michigan, the drainage canal, and Illinois, Mississippi, and Missouri rivers as made by Professors Jordan, Palmer, Gehrmann, and Burrill; had taken a journey by boat from the water front to Lockport down the drainage canal by daylight, and had followed the course of the river by trolley and train as far as La Salle, where he took a steamer and went by daylight to St. Louis, tying up at night so that no places were passed in the dark. (6907.)

The hypothetical question concerning Doctor Ravold's experiment with 107 barrels of culture of *Bacillus prodigiosus*, already cited, was given to the witness and in reply he stated that in view of the large number of bacilli introduced into the canal, the small number found showed a very considerable death rate of the germ and, by inference, at least as large a death rate of the bacillus of typhoid fever under the same circumstances. (6908–6910.)

With reference to the longevity of the typhoid bacillus witness stated that it may remain alive in the human body for many months, and in soil at least some weeks and possibly months. In water it dies out quickly en masse, although some individual cells, being more resistant, may remain alive for a longer period. The character of the water affects the longevity. In a relatively pure water the longevity of the typhoid bacillus is greater than in one where it has to fight for existence with saprophytic bacteria. It does not increase in nature outside the human body, although it may live saprophytically for a period of time varying according to its surroundings. The witness stated that the vessels in which laboratory experiments are performed, being usually small and of glass, for some reason seem to give conditions favorable to the life of the germ. Where the conditions resemble more closely those of nature, as, for instance, where a large tank is employed, the length of life of the colon and typhoid bacilli does not seem to be so great. He quoted in support of this statement some experiments made on *Bacillus coli* by the Massa-

chusetts State board of health. The vessel containing the germs was a very large one, about 12 feet deep, and was suspended in Merrimac River water. Under those circumstances it was found that the longevity of the colon bacillus was limited to eleven days. It was his belief that the typhoid bacillus would live in the water of the drainage canal and Desplaines and Illinois rivers for a shorter period of time than in sterilized water or water of greater purity from a bacteriological standpoint, and that its life would be limited to a few days. (6910–6912.)

If a river is intercepted by dams they will increase the opportunity for sedimentation, although not to an important extent. He did not believe that the amount of improvement obtained through the influence of the dams in Illinois River was very great, although it undoubtedly amounted to something. The great factor of sedimentation in Illinois River is the slope of the stream, especially in high stages, when the water overflows its banks and settles back to the right and left so that great areas of quiescent water are present and sedimentation is very marked. (6913.)

The sedimentation of bacteria was then discussed by the witness, who stated that in a clear water they will settle because they have a greater specific gravity than the water, though not much greater. This settlement is easily interfered with by currents and eddies. If the stream in question is turbid, however, the falling particles causing turbidity will unquestionably, by attaching themselves to bacteria which may be present, drag them down. The clear water from Lake Michigan discharged into Illinois River will not affect sedimentation there, because there is sufficient turbidity present in the Illinois River system to offset it. (6914–6915.)

With reference to the sanitary significance of dilution the witness stated that simple dilution is really purification, in that it diminishes the chance that the person who drinks the water, which is supposed to be polluted, will thereby contract disease. On the assumption that a glassful of water contains 100 typhoid germs, the person drinking it would run a risk that may be described by the number 100. Should 50 per cent of the germs in the water be killed the person drinking that water would drink 50 germs and his risk would be half what it was before, namely, 50. Should conditions prevail whereby no bacteria were destroyed but the volume of the stream was doubled by the inflow of pure water, then a person drinking a glassful of the mixture would have in his glass 50 germs and his risk would be 50; therefore such dilution would be productive of just as much purification as the killing of half the disease germs. The addition of Lake Michigan water to the sewage of Chicago is a benefit to the sanitary condition of Illinois River, considered both from the standpoint of dilution and from that of the chemical and bacteriological changes taking place therein. (6915–6916.)

The witness then expressed the opinion that the water of Illinois River does not have any appreciable effect, good or bad, on that of the Mississippi, although it is possible that it may slightly improve the Mississippi water, because if there is any difference between the Illinois at Grafton, the Mississippi at the same point, and the Missouri above its mouth, that difference is in favor of Illinois River. (6917.)

The witness further expressed the opinion that in his belief typhoid bacilli passing down Illinois River would die before they reached Grafton. He confined this, however, to the great mass of them. It was possible, in his opinion, that some specially resistant germs might make the journey, but most of the bacilli would perish before the Mississippi was reached. The typhoid bacillus will not live as long in polluted as in pure water, because in polluted water it has to live in the presence of many saprophytic germs, which not only monopolize the food supply but produce toxic products that are poisonous to it. There would be no material difference between the lengths of time that a typhoid bacillus would live in the sediment of a polluted stream and in the water of the same stream. The time that the bacillus would live in moist soil furnishes no criterion for its longevity in running streams; the two cases are not parallel. (6917–6919.)

If the capacity of a reservoir is equivalent to thirty days' supply of the city which it serves, it is not, according to the witness, to be assumed that the water remains stored in the reservoir for thirty days. Much depends on its construction. Many reservoirs are of the standpipe type, receiving their water and discharging it through the same orifice. Under such conditions the pumps deliver direct to the mains, and the surplus is carried to the reservoir. (6921.)

With reference to the occurrence of typhoid fever in St. Louis, the witness stated that he had noted that for the years 1899 to 1903, inclusive, the deaths from this disease had been reported as uniformly increasing, whereas in Chicago they were rather variable, indicating that there is no relation between the two places, so far as Chicago sewage being a factor in the occurrence of typhoid at St. Louis is concerned. He had noted, also, that the reported deaths from typhoid for 1900 on the three great drainage areas, exclusive of Chicago, were 503, which is more than in the preceding year. This is in accord with the reported deaths in St. Louis for 1900, which also showed an increase over those in 1899. It is not, however, in accord with the number of deaths reported in Chicago, which was smaller than in the preceding year. (6922–6923.)

The witness stated that he employed the method of giving the typhoid death rate according to the population—the number of deaths per 100,000. This is more correct than to give the percentage of typhoid deaths to total deaths, which does not enable the sanitarian to pass judgment on the conditions in a given city as to whether there

is an increase or decrease in typhoid fever. Should a certain locality have an increase in typhoid and a greater increase in tuberculosis, the report from that place would show an improvement in typhoid conditions, whereas the case would be quite the reverse. (6923–6924.)

He then presented a series of charts showing the deaths from typhoid fever in St. Louis and Chicago during each month of 1900 to 1903, inclusive. Inasmuch as by reason of the remoteness of one city from the other, an outbreak of typhoid fever in Chicago would not be reflected in St. Louis until the following month, the St. Louis tables were compiled one month in advance; that is, the February deaths in St. Louis were plotted against the January deaths in Chicago, and so on. The witness pointed out, in reviewing the evidence contained in these charts, that there is no parallelism in the curves representing the death rates in the two cities. In many instances the rise of the curve for Chicago is coincident with the falling of the curve for St. Louis, demonstrating absolutely that the one is independent of the other. (6925–6932.)

The witness presented a chart prepared from Professor Jordan's data, showing in graphic form the number of times that *Bacillus coli communis* was found in Illinois River at Pekin, Averyville, and Grafton; in Missouri River at Fort Bellefontaine, and in Mississippi River at Grafton, and at the intake tower, Missouri shore, midstream, and Illinois shore, Chain of Rocks, when operating on volumes of water varying from 0.001 to 1 c. c., and pointed out that according to the occurrence of this organism the following was the proper order of purity: Illinois River at Grafton, Mississippi River at Grafton, Illinois River at Averyville, Missouri River at Fort Bellefontaine, Mississippi River at the intake, Chain of Rocks, and Illinois River at Pekin. With reference to the sanitary significance of the colon bacillus determination, the witness stated that inasmuch as this bacillus is a constant inhabitant of the human intestine it is a valuable indicator of the presence in the water of intestinal discharges, although it bears no evidence as to whether those discharges came from a healthy or a diseased person. When this germ is found persistently in small quantities of water, such water is looked on with more suspicion, the presumption being that where *B. coli communis* is so constantly present disease germs may be associated with it. While it is true that this bacillus is widely distributed and can generally be found if enough water is examined, it is considered important to have some notion as to the volume of water examined in order to obtain an idea of the number of these germs present in the water. (6934–6935.)

As bearing on the importance of noting the interval of time elapsing between the infection of a water supply and the drinking of the infected water the witness presented the results of his review of 205 British epidemics. He had divided them into three portions—those

produced by well water, those produced by stream and r
water, and those produced by milk. There were a few out of th
ber that could not be so classified, and they were left out of co
tion. In 33 epidemics due to stream and reservoir water th
rate was 9.85 per cent of the cases; in 75 epidemics due to we
the rate was 11.83 per cent; and in the 20 epidemics due to
percentage of deaths was 12.79, showing that a well-water epi
distinctly more serious in character than one caused by strea
that had carried the typhoid germ for some distance from the
infection to the point where the water was used for drinking.
ther cited an examination which he had made of 357 cases of
fever at Waterville, Me., where he was able to follow the cours
case and to obtain the physician's statement as to whether it w
or not. Some of these patients used the city water supply fro
taminated stream, others used water from contaminated w
some used both sources. Among those who used city wa
41.41 per cent were severe cases, but among those using w
61.29 per cent were severe cases, thus showing that the fever
by city water was a mild type. The witness' explanation
was that in a river the typhoid germ had to struggle for
under adverse conditions and was not capable of producing
poisonous material when it found its seat of infection in the
(6936–6937.)

Taking into consideration the 4,846 wells in use in St. L
gether with the fact that in 1895 the city chemist had conde
he had examined, namely, 59, the witness stated that he beli
water of those wells was responsible for a portion of the ty
St. Louis, because he considered there was greater danger
from a polluted well than from a polluted stream. If, how
typhoid conditions in St. Louis during the last ten years ar
attributable to the city water, it was his opinion that wher
typhoid fever at places on the drainage area of Missouri R
Mississippi River above Grafton, nearer in point of time than
such places would be dangerous and undoubtedly the cau
disease. (6937–6939.)

The witness was of the opinion that the typhoid bacillus lyi
sediment of a polluted stream for a period of thirty to si
would not be able to retain its dangerous qualities and
typhoid fever when discharged from the bottom of the river.
not know of any instance recorded in the literature of bac
where one had lived for a period of one to three years. (6939–

He then stated that the water of Mississippi River at Chain
was not, either before or after the opening of the drainage can
domestic purposes in its raw state, and expressed the same

with reference to Illinois River at Grafton, although he thought the water had been improved since the opening of the canal. (6943–6944.)

The witness then gave opinions in disagreement with those of Professor Sedgwick, which were noted in connection with the testimony of Professor Jordan (p. 257). He made the observation that epidemics of typhoid fever due to infected water do not usually take place after great floods such as would result in the washing out of typhoid germs from the sediment of the stream, as claimed by Professor Sedgwick, and he cited the Hudson Valley as an instance where there are high floods in the spring resulting from melting snows, but the epidemics do not occur at that time of the year. In such cases as that of Tees River the conditions were quite different, inasmuch as there were great deposits of fecal matter in privies and in heaps along the shore which were washed off during high water and caused typhoid fever. But with the conditions prevailing in the Illinois River basin such a thing would not be possible. (6947.)

The witness then stated that he had information pertaining to the Detroit epidemic, given to him at the time by Prof. Gardiner S. Williams, but that he had always had doubt concerning the connection between the disease in Detroit and the dredging of Black River. With reference to the germs of Asiatic cholera and the liability of infection reaching St. Louis, should that disease become prevalent in Chicago, the witness stated that the germs would have greater difficulty in finding their way than the typhoid germs, because the latter were more hardy. (6951.)

In his opinion, the discharge of Chicago sewage by way of the drainage canal and the Illinois River system would not cause any additional expense in the purification of Mississippi water by filtration, should such a system be set up at Chain of Rocks. (6956–6957.)

CROSS-EXAMINATION.

The cross-examiner endeavored to show by a series of hypothetical questions a parallelism between the persistence of *Bacillus prodigiosus* emptied into the drainage canal and isolated from water collected at the Chain of Rocks intake and a similar presumable typhoid infection, and drew from the witness the opinion that if hourly examinations of the water at Chain of Rocks covering a period of one month should disclose the presence of typhoid bacilli on three occasions such water would unquestionably be infected with the disease. Pursuing this line the cross-examiner sought to discover why, if such were the case, the persistence of *B. prodigiosus* under like conditions, as related in the testimony of Doctor Ravold, would not show a parallelism, and therefore indicate that the water at St. Louis was polluted by the Chicago sewage. The witness replied that in his

opinion a water sampled at Chain of Rocks 720 times during the month with the identification of typhoid bacilli only twice would certainly be shown to contain typhoid infection, but not to such an extent as to be prejudicial to the city supply provided it was filtered before being used. (6957–6958.)

Summing up his opinion on the longevity of typhoid bacilli and taking into consideration the various detrimental factors naturally occurring in streams, the witness stated that the germs of typhoid fever from Chicago sewers would be destroyed en masse by the time the mouth of Illinois River was reached, although some resistant organisms might get beyond that point. They would, however, be small in number and low in vitality. The longevity of a typhoid bacillus depends, in the first place, on its parentage and next on the conditions under which it is grown. For example, a person may come from a healthy parentage and live in a healthful manner, but because of adverse conditions his vitality may be greatly lowered. In the same way the typhoid germ might struggle for existence over long periods of time, but would lose its vigor and be incapable of producing its normal amount of infection. It is, however, impossible to determine the longevity of specially resistant cells. It is probable that such cells are at the time of their departure from the human body more capable of producing disease than the greater numbers of less resistant organisms with which they start on their journey. Whether, after the interval that may be chosen for the period of investigation, they arrive in a condition to produce disease, may be open to question, because the mere fact that they are resistant and have arrived in a living condition does not mean that they will have enough toxin-producing powers left to produce that serious poison that may cause disease. All this is, however, a matter of speculation. (6958–6962.)

If a gallon of typhoid dejecta were deposited in the waters of Lake Michigan at a point free from sewage contamination, the typhoid bacteria would disappear, because they would be surrounded by myriads of ordinary saprophytic bacteria, which would set up conditions prejudicial to the life of the typhoid germs, although it is true that the life of the latter would be increased somewhat, but at all events they would disappear before the ordinary sewage saprophytes would. While it is true that the longevity of the ordinary saprophyte depends in a large measure on its environment and it dies as soon as its part in the purification of the water is finished and its food supply is gone, its disappearance takes place subsequent to that of the typhoid germ, because the latter is merely a foreigner in that locality and has no purpose to fulfill. (6963–6964.)

In analyzing the relationship between the typhoid fatality in St. Louis and Chicago the witness merely accepted the facts without reference to the temperature of the water, the variable physical conditions, or anything that happened between the two cities. Were there no Illinois River in existence, the facts would stand, and nothing is shown in the charts which enters into the question of longevity of the specific germ in passing down the stream between the two points. In the opinion of the witness such conditions are immaterial, because the typhoid figures are based on actual occurrence. (6969–6970.)

Taking into consideration all the facts with reference to the discharge of Chicago sewage in Illinois River, the witness stated that in his opinion some of the colon bacilli in the water at Averyville come from the Chicago drainage canal, but he was unable to state the proportion. (6972.)

The total number of deaths in St. Louis from 1890 to 1903, inclusive, was then recited to the witness, together with the recorded number of deaths from typhoid fever, and he was asked if it would in his opinion make any difference in the interpretation of such data whether the deaths were expressed as rate per 100,000 persons living or as percentage of typhoid deaths to total, to which he replied: "Basing my reply on the numerical data submitted in the question, it is my opinion that there is no material difference between the two methods of stating the result." (6973–6974.)

LEONARD P. KINNICUTT.

Leonard P. Kinnicutt, called as a witness on behalf of the defendants, stated that he was director of the chemical department of the Worcester Polytechnic Institute, Worcester, Mass. He graduated from the Massachusetts Institute of Technology in 1875, with the degree of bachelor of science. He studied in the University of Heidelberg for two years thereafter, under the direction of Professor Bunsen, and for two years at the University of Bonn, Germany, in the laboratory of Professor Kekule. He then studied for four months at Johns Hopkins University and later at Harvard University, where he obtained the degree of doctor of science. He was then appointed instructor of chemistry at Harvard University, and three years afterwards was called to the Worcester Polytechnic Institute. He was consulting chemist to the Connecticut sewage commission. For fifteen years he had been a fellow in the American Society for the Advancement of Science, and was a member in several American, English, and German professional societies. He had made a special study of sanitary problems since 1882, including the chemical and bacterial analysis of water, together with the interpretation of such results. He had been called to pass on the quality of water supplies

in numerous cities. He had made a study of the typhoid bacillus related to water supplies and of the colon bacillus in the determinati of the potability of water. He had thoroughly examined the phys conditions of Chicago River, the drainage canal, and Desplaines a Illinois rivers and had made extended investigations on the prob of sewage disposal, especially that of purification by means of sep tanks. It was his practice to go to England every other year study the sewage-disposal systems there and the progress made fr time to time. (7336–7339.)

The witness described the septic tank and the process of purifi tion which takes place therein, and discussed the sewage-dispo problem in some detail. He then gave the results of his observati on the Chicago drainage canal, and compared it to a septic ta He stated that as he passed along the canal in a truck boat, he served the indications of septicity therein. He noted that gas being given off from the liquid at the upper end of the canal, t ical of septic-tank gas, and that after passing Lemont the changed to that of the effluent of a sedimentation tank. He then sented a series of tables to bring out these facts. The data in 86 were taken from the results of examinations by Professors Jo Palmer, and Long, and show the comparative conditions at the and lower ends of the canal. (7340–7348.)

TABLE 86.—*Analyses showing changes in the character of sewage during its through the Chicago drainage canal, being the mean of results obtained by P Jordan, Long, and Palmer.*

[Parts per million.]

Constituents.	Kedzie and Western avenues.	Lockport.	Parts removed.
Solids:			
Total	207.0	200.7	6.3
Soluble	179.2	184.4	+5.2
Suspended	27.8	16.3	11.5
Oxygen consumed:			
Total	7.93	6.26	1.67
Soluble	4.77	4.63	.14
Suspended	3.16	1.63	1.53
Nitrogen:			
Free ammonia	1.20	1.57	+.37
Total albuminoid ammonia	.58	.45	.13
Nitrites	.050	.024	.026
Nitrates	.23	.097	.133
Albuminoid ammonia (mean of Jordan's and Palmer's results, Long not determining soluble and suspended albuminoid ammonia):			
Total	.48	.37	.11
Soluble	.20	.165	.035
Suspended	.28	.205	.075

TABLE 87.—*Comparative action of the septic tank and the Chicago drainage canal on removal of sewage.*

[Per cent removed.]

Constituents.	Birmingham.	Exeter.	Leeds.	Manchester.	Worcester (Kinnicutt, 1900–1901).	Lowell (Clark, 1900–1901).	Drainage canal.
Solids:							
Total	26.0	24	34	27	22	.....	3.0
Soluble	8.0	7	12	15	21	.....	+ 2.9
Suspended	60.0	60	70	57	26	.....	41.3
Oxygen consumed:							
Total	33.6	.....	.....	.....	36	45	21.0
Soluble	25.4	.....	.....	.....	29	.....	2.9
Suspended	57.1	.....	.....	.....	44	.....	48.0
Nitrogen:							
Free ammonia	+24	.....	22	.....	+20	0	+32.7
Albuminoid ammonia	41.6	17	59	.....	33	55	21.8
Albuminoid ammonia:							
Total	.....	.....	.....	.....	33	.....	22.8
Soluble	.....	.....	.....	.....	8	.....	17.5
Suspended	.....	.....	.....	.....	43	.....	26.7

Commenting on the above tables, the witness stated that if analyses are made of crude sewage and of effluents from the septic tank it is found that the amount of free ammonia in the effluent is greater than in the sewage, but the amount of total or soluble albuminoid ammonia is less in the effluent. The nitrogen as nitrates and nitrites is very small in the effluent as well as in the sewage, but there is a reduction in both. The results in the tables indicate very strongly that septic action has taken place during the passage through the canal of water containing sewage, as is shown by the increase in free ammonia and oxygen consumed. The results agree in other general characteristics with those that have been obtained from septic tanks at various places, as shown in Table 87. In other words, the canal has a purifying effect and renders substances that still remain in the sewage more easily acted on when they are discharged into the river. The purification of the sewage by the canal consists of the removal of a part of the solid matter by throwing some of it down to the bottom of the canal and by changing some of it to gases. Very little work has been done with reference to the effect of the septic tank on bacterial life. The second report of the royal commission on sewage disposal of Great Britain quotes experiments made in Manchester, England, showing that the *Bacillus coli communis* diminishes during the septic period, and the same effect must be felt by the similar and more delicate bacteria such as that of typhoid fever. Similar results are shown at Leeds. The witness's opinion was that the septic tank reduces the number of *B. coli* and the more delicate pathogenic germs, and that the total number of bacteria is diminished by 10 or 15 per cent. (7348–7350.)

The witness then took up in detail the results of examinations presented in evidence by Professors Jordan, Palmer, Burrill, Zeit,

and Long, assembling the data according to the average determinations and according to various combinations in many tables and charts and discussing in connection therewith the significance of the results. This discussion appears in the record, pages 7354-7446.

In his final summing up of the evidence contained in the tables and charts just referred to, the witness stated that about 20 per cent of the organic matter discharged into the drainage canal from the sewers of Chicago disappears in the canal, this percentage being measured by both the loss in albuminoid ammonia and the loss in oxygen consumed. A certain amount of suspended matter also is removed and further amounts are rendered soluble and converted into gases. This not only purifies a part of the sewage, but changes the remainder so that further purification will take place more easily on its discharge into Desplaines River. Undoubtedly, in the upper stretches of the river near Joliet, both aerobic and anaerobic actions are taking place. Farther downstream—at Ottawa, for example—the action is principally aerobic, and in both 1899 and 1900 this point was the center of the zone of greatest decomposition. Purification continues until Averyville is reached. Below Peoria the process is repeated, until at Grafton all the original organic matter which was in the river at Pekin has been decomposed and changed. The effect of emptying the sewage of Chicago into Desplaines River is to increase the amount of organic matter in the upper stretches, but such addition is not noticed at Averyville except in the increased nitrogen contained in the river. At Grafton the effect of the addition of sewage to Illinois River can be seen only in the high chlorine and nitrogen as nitrates. This nitrogen is very different from that at or above Ottawa, having been changed over and over again from its original character. The chart representing Illinois River, May to August, 1899 and 1900, before and after the opening of the drainage canal, shows that the purification took place in almost exactly the same way during those two periods. Such nitrogen and chlorine as are found in the river at Grafton are not in the slightest degree dangerous to public health and can have absolutely no effect on the human system. (7446-7449.)

The witness stated that he had studied the determinations of *Bacillus coli communis* given in the testimony of Professor Jordan and also the experiments on the viability of typhoid germs made by Professors Jordan, Russell, and Zeit, and as a result thereof was convinced that no deleterious matter persisted down Illinois River as far as Grafton. All the data that he had examined showed that the water at Grafton does not contain undecomposed matter, and it was therefore his opinion that the water of Mississippi River at the Chain of Rocks intake had not been made less valuable for drinking

purposes or more liable to carry water-borne diseases than before the opening of the drainage canal. He considered that an increased speed of Illinois River caused by the addition of water from the drainage canal would not have any effect in increasing or diminishing the number of typhoid germs or the liability to typhoid and other water-borne diseases on the part of the inhabitants of St. Louis. (7449–7450.)

The witness then expressed his disagreement with Professor Sedgwick's statement that the typhoid germ may live in sewage-polluted streams for weeks, months, or even years, because all the experiments with which he was familiar showed that the typhoid germ will live a shorter time in polluted water than in pure water. He further disagreed with Professor Sedgwick by stating his belief that a typhoid bacillus would not live from the time it left the Chicago sewers until it entered slack waters at Peoria, and that even should it survive the passage to this point and be deposited upon the bed of Lake Peoria, it would not live for a period of a month in such a deposit. In this connection he cited an experiment described in the Thirty-fourth Annual Report of the Massachusetts State board of health, in which polluted water was allowed to stand in a large storage reservoir without further pollution and the colon bacilli rapidly decreased and none were found after eleven days. He also disagreed with Professor Sedgwick's statement that the waters leaving Lake Peoria would at times, by reason of the accumulation of bacteria in the lake, be more infectious than those discharged from the Bear Trap dam, and declared that he knew of no evidence, scientific or other, that would show that germs of typhoid fever would remain upon the bottom of streams, lakes, or slack-water basins for a long period and then be washed out in a virulent state and be dangerous to people consuming the water. (7451–7453.)

The witness stated that the analytical evidence presented by the defendants showed that Mississippi and Illinois rivers above Grafton contain practically the same amounts of impurity and that Missouri River at Fort Bellefontaine contains a much larger amount than either of the others. Therefore the mixing of the waters of the first two streams with that of the Missouri would improve it as a water supply for St. Louis. (7459.)

In the opinion of the witness, the water of Mississippi River at the Chain of Rocks intake was not suitable for drinking purposes in its raw state, either before or after the opening of the Chicago drainage canal. (7462–7463.)

The cross-examination was waived.

THEOBALD SMITH.

Theobald Smith, a witness on behalf of the defendants, stated that he was a professor in the Harvard Medical School and pathologist of the State board of health of Massachusetts, which position he had held since 1895. Prior to that he was bacteriologist in charge of the investigations of the Bureau of Animal Industry, United States Department of Agriculture, and at the same time professor of bacteriology in the medical department of Columbian University. He graduated from Cornell University in 1881, spent two years in the study of medicine at Albany Medical Colloge, spent six months in special work at Cornell, and went to Washington in the fall of 1883. He had become interested in the bacteriology of water in 1886, when he made observations on Potomac River, and in 1891 he was engaged for a number of months on a sanitary survey of Hudson River between Schenectady and Albany. During the year previous to the date of testimony he was engaged in looking over the bacteriological and general sanitary status of Charles River basin, around Boston. During all this period of investigation the main question involved had been the bearing of drinking water on typhoid fever and other intestinal infections. (7288–7290.)

The witness then stated that in considering the sanitary condition of a water he had taken it for granted that the most important indication of its pollution would be the presence of fecal matter, because the bacilli of typhoid fever, dysentery, Asiatic cholera, and various diarrheal diseases are involved, and any test that would indicate the relative number of these bacteria would bring the observer as nearly as possible to an exact determination of the condition of the water. In the study of fecal bacteria there is one bacillus of intestinal origin the isolation of which affords as accurate a judgment as possible of the sanitary quality of a water. This is *Bacillus coli communis*, a species closely allied to and a probable progenitor of *B. typhosus*. In view of the fact that bacteriological methods are still unsatisfactory in the isolation of the typhoid bacillus, it is not practicable to attempt such determinations on a large scale, but the presence of the colon bacillus affords information nearly as conclusive. He then described the tests for distinguishing between the two organisms. With reference to their comparative longevity, he stated that the typhoid bacilli are more perishable under a variety of conditions. (7290–7292.)

The witness defined the bacterial self-purification of streams as a reduction in the number of bacteria in a stream, which is not due simply to perfect or imperfect sedimentation, but to the complete disappearance or destruction of the bacteria in the water. He did not know of any general principles involved, and was of the opinion that each stream has certain special local conditions that require investigation and that depend on a number of factors which vary from stream to stream, so that an individual investigation of each stream by itself

is necessary. He expressed the belief that the study of Illinois River between Chicago and Grafton was the most extensive ever made, and laid stress on the examination for *B. coli communis* as especially applicable to such a problem. (7295–7296.)

With reference to the failure to find the colon bacillus in Mississippi River above New Orleans, the witness stated that the results would lead to the belief that all the other closely related bacteria, such as the typhoid and dysentery bacilli, had also disappeared. (7296.)

The typhoid bacillus will not reproduce its kind in ordinary water, but will grow rapidly in milk until the milk becomes very acid. In general the typhoid bacillus does not increase outside of the human body except in favorable culture media. (7297.)

The witness stated that he would assume, from the data introduced in the testimony of Professor Jordan relative to the numbers of colon bacilli in the waters of the drainage canal and Illinois, Mississippi, and Missouri rivers, that these bacilli had so largely disappeared in their passage down Illinois River that they were less numerous in this stream at Grafton than in the Mississippi above Grafton or in the Missouri at its mouth. Therefore it would seem to him that the water at the mouth of Illinois River was certainly not inferior to that in the other two streams, but, on the contrary, more pure. If virulent typhoid bacilli should actually pass from Chicago to the mouth of Illinois River, such passage would be made according to conditions and laws of which the profession knows nothing; but, basing his opinion on the close relationship of the colon bacillus to the typhoid bacillus and to this entire group of disease germs, he believed that he was justified in stating that virulent typhoid bacilli would be very largely destroyed before reaching Grafton. If a typhoid bacillus should be discovered in the water supply of St. Louis or in Mississippi River at Chain of Rocks, it would be utterly impossible to identify its source, but the presumption would be that it had come from the nearest town discharging sewage. On the whole, the passage of a typhoid bacillus from Chicago to St. Louis was entirely out of probability. (7297–7301.)

The witness then stated that the question concerning the effect of polluted water on the life of the typhoid bacillus is very difficult to answer categorically, inasmuch as it depends on the temperature and the amount of pollution. It is probable that if the pollution were very great the typhoid bacilli under very favorable temperature might begin to multiply after a short period of time, and in the course of this multiplication would become destroyed, because they would render themselves vulnerable to destruction—that is to say, it is possible that sewage might offer enough stimulus to these bacteria to induce them to multiply and then become destroyed. The history of typhoid epidemics had shown that typhoid bacilli can be carried by relatively

[illegible] epidemics at Ithaca and Plymouth, but whether [illegible] to the destruction of the bacteria o[illegible] which he did not feel competent to [illegible] 7301–7303.)

[illegible] sewage was the cause of typhoid fever [illegible] a relationship between the occurrence of [illegible] point of time. The curves diagram[illegible] deaths would be synchronous, although [illegible] slightly retarded, because of the distance [illegible] period of incubation of the disease. He [illegible] between these two cities along this [illegible] St. Louis charts seems to correspond [illegible] increase manifested throughout the [illegible] to the occurrence of the disease.

[illegible] typhoid fever on the three great [illegible] the witness stated that he would not [illegible] public use without previous purifi[illegible] trace out the sources of infection [illegible] points nearer than Chicago. [illegible] typhoid bacillus in water, the far[illegible] less would be the danger of disease [illegible] bacteria discharged into the stream [illegible] more dangerous than a large number [illegible]

[illegible] Professors Jordan, Russell, and [illegible] bacteria as determined by the use of [illegible] that a new factor had been intro[illegible] and that they had defined, for the [illegible] the bacterium in polluted water. [illegible] he stated that he felt prepared [illegible] opinion that it would be phys[illegible] starting from Chicago to reach [illegible]

[illegible] out on cross-examination.

[illegible] SMITH.

[illegible] on behalf of the defendants, [illegible] at Beloit College, Beloit, Wis., [illegible] 1881. He had graduated from [illegible] studied under private tutelage. [illegible] chemistry to Williston Seminary at [illegible] for three years and then going to [illegible] degree of doctor of philosophy at Georgia

Augusta University, Germany, in 1883, and had taken a course in bacteriology during one summer at the Massachusetts Institute of Technology. Since 1885 he had given practically all his available time to the study of sanitary problems, especially those related to watercourses. In connection with his studies he had been called to investigate many public water supplies, including those from both surface and underground sources. He had investigated typhoid fever epidemics at numerous places and gave extended accounts of each during his testimony. In addition to this he had acted as consulting chemist in connection with water-filtration plants at Rock Island and Kankakee, Ill.; Ashland, Eau Claire, Oshkosh, and West Superior, Wis.; Independence and Burlington, Kans.; Cedar Rapids and Burlington, Iowa; Beaver Falls, Pa.; Warren, Ohio; Brooklyn and Binghamton, N. Y.; and Denver, Colo. He had also studied filtration systems at London, Paris, Antwerp, Berlin, and Hamburg. (6736–6745.)

The witness stated that he had studied the chemical and bacterial analyses of the waters of Lake Michigan, the drainage canal, Desplaines, Illinois, Mississippi, and Missouri rivers, as presented in the testimony of Professors Jordan, Gehrmann, Palmer, and Burrill, and was thoroughly acquainted with all the bodies of water mentioned. He had made a trip from the mouth of Chicago River along the entire course as far as Eads Bridge, St. Louis. (6745–6746.)

The attention of the witness was directed to the *Bacillus prodigiosus* experiment made by Doctor Ravold on behalf of the complainant. He stated that this bacillus is an organism not widely distributed in nature, although it occasionally does occur. He was not sure whether he had found it himself in river waters, but had found a form closely allied to it. In his opinion the *prodigiosus* experiment did not possess value with reference to the probable longevity of the typhoid bacillus. The longevity of *B. prodigiosus* is not necessarily a measure of that of the typhoid bacillus, and the results of the experiment, on the assumption that the facts as presented by Doctor Ravold are true, do not contribute to the probability that a typhoid bacillus entering the drainage canal would find its way to the intake of the St. Louis waterworks. On the contrary, it seems highly improbable that such would be the case, because, although *B. prodigiosus* is known to flourish in water under ordinary temperature when the proper nourishment is available, there is no evidence showing that the typhoid organism flourishes under similar conditions. With reference to the experiment itself, the witness stated that there was nothing in the results to show that the bacilli alleged to have been found were those that were placed in the water of the canal, because there is evidence that they are occasionally found in natural water. On studying the question, it seemed to him

that if these bacilli had remained in the water for any length of time they would have been found farther up the river, but no such identifications were made above Grafton, although they were diligently searched for in the water at Joliet. (6747–6750.)

The presence of the colon bacillus in water is very significant because it is the constant inhabitant of the intestinal tracts of man and of most domestic animals and is not present, certainly in any number, in a natural unpolluted water. There is a question whether some fish do not excrete them in small numbers and therefore the colon bacillus is occasionally found in an unpolluted water. Under ordinary circumstances, however, the discovery of this organism in a natural water is presumptive evidence that fecal matter as sewage has found its way into that water. (6751.)

According to the work of Doctor Frankland, the typhoid bacillus has been observed in water previously sterilized after a period of one hundred days, and this may be taken as the maximum recorded time. In unsterilized water it would diminish in numbers and disappear after a few days, some records specifying it at six or seven days and some as high as twenty-six days. The bacillus does not multiply and increase in water. Laboratory conditions are rather more favorable for its longevity than those met with in nature. One of the reasons for this is that the glass itself seems to affect the water. There are other conditions, such as uniformity of temperature and environment, neither of which prevail in a running stream. Experiments show that the typhoid-fever germ will not live as long in polluted as in sterilized water, the reason probably being that the organism in polluted water is subject to certain enemies, namely, the toxins thrown off by the other bacterial forms, as well as the varying conditions of the stream. (6752–6753.)

The witness stated that from such study as he had been able to make of the quality of water in the drainage canal and Desplaines and Illinois rivers and from a study of the work of Professor Jordan it was his opinion that the duration of life of the typhoid bacillus must be brief in those streams, amounting to but two or three days. This he believed to be due to the toxic effects on the typhoid organisms of the other organisms in the stream. (6753–6754.)

The effect of the dams erected across Illinois River would naturally be to increase the amount of sedimentation by bringing the water into a more quiescent condition. A high water always tends to increase the amount of sediment contained in a river, but the physical surroundings of Illinois River compensate for this increase of sediment, because during high water the stream overflows and there is an enormous amount of sedimentation on the overflowed lands. Bacteria will respond to the law of gravity, for they are somewhat heavier than water, but this response takes place slowly except in water practically

quiescent. The tendency of bacteria is downward, however, even in a running stream. The settlement of matter in suspension greatly assists the sedimentation of bacteria because the organisms fasten on the particles of suspended matter and are carried downward. (6754–6755.)

In reply to a question concerning the effect of the discharge of clear water from Lake Michigan on the rate of sedimentation in Illinois River, the witness stated that the amount passing through the drainage canal could not produce a condition of sufficient clearness in the river water to preclude the possibility of the opportunity for sedimentation. Even if the entire sewage of Chicago could be diverted into the drainage canal and 800,000 cubic feet of water per minute from Lake Michigan should pass over the Bear Trap dam the dilution caused thereby would not be sufficient to prevent the sedimentation of bacteria in the river. (6756.)

The dilution of the water of a river with another water of pure quality is one of the well-recognized factors in the problem of self-purification of streams. It separates the different micro-organisms, and thus diminishes the liability of their being taken into the animal economy. Sewage-laden water diluted with water of a better quality is thereby rendered less liable to communicate disease by infection. Therefore the addition of the pure Lake Michigan water to the Chicago sewage improves its quality, because the dangerous micro-organisms in the sewage are more widely separated from each other, and also because it gives the river greater room for facilitating the sedimentation of the solid matter in suspension, thereby decidedly improving the sanitary condition of Illinois River from the standpoint of the chemical and bacteriological changes taking place. (6757–6758.)

In the opinion of the witness, it seemed very clear that there is no pollution dangerous to public health from the drainage canal persisting in Illinois River as far as Grafton, for the reason that the natural conditions of the stream are such as to facilitate the dilution, sedimentation, and oxidation of the sewage matter. In addition to this, experimental work shows that the life of the typhoid bacillus in this stream probably does not exceed three days. The result of all this is that the water of Illinois River at Grafton appears, from all chemical and bacteriological standpoints, to be equal in quality to that of tributary streams in the valley. These conditions would persist even in the event of low water in Missouri River at a time when Illinois River was in flood stages, because even under such flood conditions the purifying agencies would still be effectual. Therefore, in the light of all the conclusions above given, the witness stated that the sewage from Chicago could not affect the water supply of St. Louis nor the waters of the Mississippi as they pass along the border of the State of Missouri. (6760–6762.)

The witness stated that in his opinion the typhoid bacillus would live longer in the sediment at the bottom of a stream than it would in the water itself, for the reason that the changes taking place in the sediment are not so great nor so constant as in the water. Of course a bacterium deposited in such sediment would be affected by the same agencies, namely, the toxic products of other bacteria, as in the water of the stream itself, but probably to a less degree, so that the absence of these destructive agencies would prolong the life of the organism in the sediment of the stream, but not for any great length of time. (6764.)

The witness expressed agreement with Professors Jordan and Russell in stating that the typhoid organisms would live longer in moist earth than in the sediment of a stream, because of the fact that the particles of moist soil are separated by thin layers of air, which tend to diffuse the toxic agencies of other bacteria less rapidly than water. The particles of sediment in the bottom of the stream are all surrounded by water and the conditions of diffusion are practically the same as in the water of the stream itself. It was his opinion, however, that the period during which the typhoid bacillus will live in moist earth does not furnish any criterion for its longevity in the sediment of a running stream and that the two conditions are in no way comparable. (6764–6765.)

In giving mortality statistics, the witness's preference was for the use of the rate per unit of population rather than the mortality percentage method, for the same reason as had been expressed by other witnesses for the defense. He also thoroughly agreed with Professor Russell in his opinion of the danger of typhoid-fever infection from rural communities, and gave various cases in which such infection had caused epidemics. (6767–6770.)

With reference to the position occupied by the science of bacteriology in regard to the ascertainment of the purity of river waters, the witness stated that it is commonly accepted that diseases are caused by certain specific organisms and that among these organisms which can be borne by water are those of typhoid fever and cholera. These are intestinal diseases, and therefore it is very important to determine whether or not fecal matters find access to the water. The presence or absence of the intestinal bacteria can be used, therefore, as the most important index in determining the purity or impurity of the supply. (6770.)

The witness then stated that the science of chemistry as applied to river water has to do with the determination of the presence or absence of organic matter in that water. It is necessary to know the chemical constituents of water from a sanitary standpoint and whether or not the water contains organic matter. It may or may not be possible to determine the bacterial forms present in the water, but the pres-

ence or absence of organic matter can be determined. Another application of chemistry is to determine what changes the organic matter undergoes after a period of time. A sanitarian could hardly form a proper opinion regarding the quality of a river water did he not have chemical and bacteriological data on which to base such an opinion. As an example of this witness cited the South Platte River, at Denver, Colo.—a bright, clear, stream flowing from a mountain spring through unoccupied land. The water is entirely satisfactory in appearance, but on bacteriological examination is found to be polluted with sewage. Chemical evidence is confirmatory of this, and it is thereby shown that the water is unfit for domestic consumption in its raw state. (6771–6772.)

In the opinion of the witness, the chemical and bacterial data submitted by the defendants show that the waters of Illinois River have become practically purified of Chicago sewage before reaching Peoria, and therefore could not become a menace to the inhabitants of the State of Missouri. This being the case, the same would be true at the mouth of Illinois River, and in his opinion the Illinois River water at Grafton discloses a smaller amount of impurity than that of the Mississippi above the mouth of the Illinois or that of the Missouri above its confluence with the Mississippi. Therefore, if the data show that there is a gradual mixing of Illinois River water with that of the other two rivers, the tendency would be to improve the quality of the combined waters. (6772–6775.)

The witness then reviewed the facts with reference to sewage pollution in Mississippi River above the mouth of Illinois River, stating the extent to which polluting materials were discharged and their effect on Mississippi River water. In his opinion, the Mississippi water is unfit for drinking and domestic purposes in its raw state. (6775–6785.)

With reference to the opinion expressed by Professor Sedgwick, that the germs of typhoid fever could lie in the sediment of the drainage canal and upon the bottom of Illinois River for a period of one to three years and then be washed out and pass down the river in a virulent condition, the witness said:

From the experiments already given upon the life of the typhoid-fever germs in the Illinois River after the same has received the sewage of the city of Chicago, from the fact that the germs which may have been precipitated to the bottom of the river in the sediment of the river would be measurably subject to the same agencies, the same tending to its rapid destruction, it is my opinion that there is no probability or possibility of a germ remaining at the bottom of the river for a period of from one to three years. I know of no instance on record or in literature where a typhoid bacillus has lived for a period of from one to three years in the sediment of a polluted stream or in the water of the same; but on the contrary, the records of all the experiments which I have been able to read and from all information I have been able to gather upon the subject of the duration of the life of a typhoid-fever germ in a polluted water is that it is brief, being limited to that of a few days, six or seven, perhaps, at the outside. (6785–6786.)

The water from Mississippi River at Chain of Rocks was not prior to the opening of the Chicago drainage canal a safe and potable water for domestic purposes in St. Louis. The opening of said canal had not created any greater necessity for the purification of this water for municipal purposes than existed prior to such opening, and in the event that a filter should be established at St. Louis the cost of operation would not be increased by the discharge of Chicago sewage into the Illinois River basin. (6791–6796.)

The witness then reviewed the analytical data presented by Professors Jordan, Long, and Palmer, and introduced into the record and discussed tables of averages, his conclusions being the same as those already submitted by the above-named witnesses. (6796–6811.)

In response to leading questions the witness discussed further the improbability of there being any damage caused to the St. Louis water supply by reason of the discharge of sewage into the Illinois River basin, but as the matter is largely repetition it will not be reviewed here. (6811–6828.)

No important new facts appear to have been established on cross-examination.

GEORGE DOCK.

DIRECT EXAMINATION.

George Dock, a witness called in behalf of the defendants, qualified as an expert by saying that he had been connected with the medical faculty of the University of Michigan for thirteen years, and at the time of the testimony held the chair of theory and practice of medicine. He graduated from the medical department of the University of Pennsylvania in 1884; spent one year after graduation in St. Mary's Hospital, which is situated in and receives the patients from the most afflicted typhoid district in Philadelphia. He gave especial attention to this disease during his period of service in this hospital. He then went to Germany and for two years studied medicine at Leipzig, Berlin, Vienna, and Frankfort. During his attendance at Leipzig and Berlin typhoid fever was epidemic and excellent opportunities were afforded him for the study of this disease. Returning to Philadelphia, he became connected with the hospital of the University of Pennsylvania, and during the period of his service there he had an unusually large practice among typhoid-fever cases. At this hospital he began the study of malaria, and in order that he might have a good opportunity to study that disease he went to Galveston, Tex., and became professor of pathology in the Galveston Medical School and physician in the hospital. After his services at Galveston he accepted a position at the University of Michigan, where he had remained up to the date of the testimony. During the Spanish-

American war he was engaged by the Surgeon-General of the United States Army to visit the military hospitals at Chickamauga, Knoxville, and Camp Meade, and there added to his already ripe experience in the diagnosis of malaria and typhoid fever. (7044–7050.)

The witness then entered on a discussion of the diagnostic difficulties in typhoid fever and malaria. He found at Galveston practically no typhoid fever reported, but an unusually large amount of malaria, nearly all of which proved on examination to be typhoid fever. On going to Ann Arbor he found this experience repeated, with the difference that although he had in Galveston found a few cases of actual malaria, he found not a single fatal case among all those reported as such in the State of Michigan. (7045–7046.)

The entire subject of the occurrence of malaria throughout the Mississippi Valley had been thoroughly studied by him and he had given, special attention in years past to St. Louis by visiting the city frequently, inspecting and conferring personally and by letter with the physicians there. He found that in St. Louis malaria was very rare, and it was likely that nearly all the supposed cases were typhoid. (7046–7049.)

In his examination of the army hospitals in 1898 he found that at Chickamauga out of 400 cases diagnosed as malaria there was only one actual case, the remainder being typhoid. At Camp Meade there were during his period of inspection several hundred cases diagnosed as malaria, all of which except one were typhoid, while at Knoxville he found not a single case of malaria. (7049–7050.)

Continuing, he stated that the terms "intermittent," "remittent," "typho-malarial," "congestive," and "simple continued" fevers were entirely unsatisfactory and did not represent specific types and that they nearly all mean typhoid fever in the vital statistics reports. Malaria appears as remittent and sometimes as intermittent, but so does typhoid, and therefore any of the symptoms noted under the above terms were not, as specified, all malarial exclusively. (7051–7053.)

Hypothetical questions were then asked, based on a statement of the number of deaths reported from typhoid and the malarial diseases, above named, in St. Louis. These figures are given in Table 80 (p.242). In reply the witness made the following comments:

From 1895 to 1903 the record shows a steady and gradual increase in the number of cases, but no sudden or disproportionate increase. Since 1898 there had been a much larger number of typhoid cases reported all over the country, owing to an increased knowledge of the disease, resulting from the lessons of the war with Spain. At that time the attention of the profession generally had been called to the diagnostic procedure in typhoid cases, which had resulted in more

accurate observations and, consequently, more typhoid reports. This explained in a large measure the increase in the number of St. Louis cases since 1898. (7054–7055.)

The witness stated that typhoid tables should contain most, if not all, of the so-called "malarial" deaths. The malarial rate shown in Table 80 is entirely too high for every year, and the probability of these being actual typhoid cases is apparent. As an example, he noted the great increase in typhoid in 1890 to 1892 due to specific causes and, together with that, the concurrent increase in so-called "malarial" diseases. During that period there was no reason, according to the witness, for believing that malaria should rise to so great a height, and the increase was undoubtedly due to mistaken diagnosis, the cases being really a part of the typhoid epidemic. In addition to this, he made the point that fatal malaria or remittent malaria occurs rarely above the latitude of Arkansas. North of this parallel nearly all the malarial cases are intermittent and almost never fatal. Therefore the impossibility of so many deaths from malaria at St. Louis was evident; they must have been from typhoid fever. The only city in the United States showing so much malaria is New Orleans, where conditions for the encouragement of this disease are extraordinarily good and where the physicians are subject to the same diagnostic errors as in St. Louis. Statistics and his own experience show that 50 to 90 per cent of the so-called "malaria" in the United States is really typhoid, and only 2 or 3 per cent actually malaria. (7055–7059.)

On the assumption that all the deaths represented in Table 80 were typhoid, there was no marked increase in any one year, although the total had gradually increased since 1898, for reasons already explained. With reference to Table 79 (p. 241), introduced into evidence by Professor Jordan, showing the monthly distribution of deaths from typhoid and malarial diseases, the witness stated that it showed even more clearly the probability that the most of the so-called "malarial" diseases were actually typhoid, because so many of the alleged malarial deaths occurred during January, February, March, and April. No one, in the opinion of the witness, dies of malaria in the latitude of St. Louis during those months. Even in the Philippines malaria is not fatal throughout the year. The circular letters sent to the physicians of St. Louis by the local health commissioner in 1900 and 1901, calling attention to the fact that the law requires them to report cases of deaths from typhoid, would explain the rise that had occurred in the last two years. These circulars were issued approximately at the opening of the Chicago drainage canal, and the result would make it appear that the discharge from that canal was responsible for the increase. Nevertheless, the increase was not as great as

might be expected, and considerably less than had been found to take place in other cities in which similar circulars had been sent. (7059–7063.)

The witness considered it especially significant that the number of recorded deaths from malarial diseases should have decreased as shown by the death table, and he testified strongly to the effect that the errors made by physicians in diagnosis had been in a large measure corrected and that the cases formerly charged to malarial diseases were now to some extent being given their correct designation. (7063.)

Another table was introduced into evidence, showing the population and deaths per 100,000 of typhoid fever alone during 1890 to 1893, together with the record of typhoid fever, plus 50 per cent of the deaths recorded under the heading "intermittent fever," etc., and of "typhoid fever," plus all the deaths recorded under that heading. The witness repeated his opinion that such tables showed only the slight increase that would be ascribed to increased care in diagnosis rather than to any outside conditions. One of the most serious sources of typhoid fever in St. Louis, according to the witness, was the water from wells. (7064–7066.)

The following appears in the record, page 7066:

Q. Assuming that on April 1, 1895, the total number of wells in the city of St. Louis was 4,846, and assuming that pursuant to an order of the board of health of St. Louis directing an examination of these wells, the city chemist, after examining 59 wells, condemned them as unsanitary, and assume further that in August, 1895, upon the report of the city chemist, condemning 7 more of these walls, the board of health of St. Louis passed a resolution that the city should make no further examination of the wells in question, and since August, 1895, none of these wells have been condemned, what effect would this number of wells in the city of St. Louis have, in your opinion, upon the typhoid conditions existing in said city, assuming that the water of these wells was used by the inhabitants for drinking and domestic purposes?

A. It would be a very serious source of typhoid fever.

In concluding his direct testimony the witness stated his opinion that the increase in typhoid fever indicates rather a change in the conditions of the city of St. Louis itself rather than in the main water supply. If the main water supply comes from the river, a change for the worse in the conditions of the river water is always indicated by a more marked increase in the disease. As to such an increase as was shown here, it is altogether compatible with changing local conditions, such as wells, and the ordinary course of typhoid epidemics. (7066–7067.)

CROSS-EXAMINATION.

The witness admitted, in response to leading questions, that he had never practiced medicine in St. Louis, and that the only investigations of mortality which he had made were those of the figures

submitted to him, including a study of the published reports. While he would not state that all the physicians in St. Louis were not competent to make a distinction between typhoid and malaria, he did contend that a large number did not make correct diagnoses. (7067–7070.)

While the witness admitted that the records for typhoid-fever deaths showed during the four years prior to the opening of the canal an average of 22.8 per 100,000 and during the four years immediately following an average of 36 per 100,000, indicating an increase of about 74 per cent, this was not what he would call a large increase. Although it would be an increase for the town and from the standpoint of the people who were sick, it would not necessarily indicate a radical difference in the matter of infection. Where a change takes place in the method of infection in a town that always has typhoid, the change is much greater than this, usually several hundred per cent, and at least more than 100 per cent. For example, a difference of seventy-odd per cent might easily occur in a place like Chicago or Philadelphia and mean no increase in the method of infection. (7073–7077.)

REDIRECT EXAMINATION.

On redirect examination the witness objected to observations based on averages for the entire four years preceding and the four years succeeding the opening of the canal and stated that the increase did not occur in a single year, but was spread over a series of years. If the 73 per cent had occurred between 1899 and 1900, it would be his opinion that there must be a new focus of infection, but inasmuch as it was spread over four years, and the ascent was gradual, he adhered to his statement that it was not a great increase. A correct idea of the increase could be gained only by calculating the relationship existing between each year. The percentage for long periods is a doubtful one. There might be local conditions in any one year that would offset the average too much. In all such specifications there is a very serious error, depending on the comparatively limited number of cases considered. (7077–7079.)

The witness further mentioned the fact that during the years 1901, 1902, and 1903 the Louisiana Purchase Exposition affected the rate, in that the desire was to maintain a low record of typhoid and the tendency was therefore to report typhoid fever by some other name, so that the increase according to the record was probably not as great as the actual increase. (7058.) This was conceded by counsel. (7081.)

LEWELLYS F. BARKER.

Lewellys F. Barker, called as a witness on behalf of the defendants, stated that he was professor of anatomy in the University of Chicago, and had been in charge of that department for three years. Previous to going to Chicago he was for nine years associated with the medical faculty of Johns Hopkins University, being for the first year assistant to Prof. William Osler in the department of internal medicine, for the next two years a fellow in pathology and bacteriology with Prof. William H. Welch, then associate in anatomy with Professor Mall, next assistant professor of anatomy, and finally associate professor of pathology. He had graduated from the University of Toronto and had served one year as house physician at the Toronto General Hospital. During his services in Baltimore he was on leave at various periods studying in Germany and on various commissions. His first commission was one established by the State board of health of Maryland when he and Prof. Simon Flexner were sent to study an epidemic of cerebro-spinal meningitis. In 1899 he and Doctor Flexner were sent by Johns Hopkins University to study tropical diseases in the Philippine Islands and incidentally the epidemics of plague and beriberi in Hongkong, India, and Japan. While in Manila he had abundant opportunity for the study of typhoid fever, malaria, and acute tropical dysentery. Subsequently he was appointed by the Secretary of the Treasury on a commission with Professor Flexner, of the University of Pennsylvania, and Professor Novy, of the University of Michigan, to study the bubonic plague in San Francisco. (7082–7087.)

The witness stated that the terms remittent, intermittent, typhomalarial, congestive, and simple continued fevers were all clinical rather than pathological and date back to the time when classification of diseases had to be made by symptomatology rather than by pathology. He defined the various terms and stated that they had all been given up by good clinicians at the present time. They all represent either typhoid, malaria, or acute tuberculosis, but most often they represent typhoid. (7090.)

The witness presented the St. Louis statistics covering the years 1890 to 1902, inclusive, giving deaths in which the cause was diagnosed as typhoid fever and the total deaths the cause of which was diagnosed as the febrile diseases mentioned in the preceding paragraph. These figures are given in Table 80, in the testimony of Professor Jordan (p. 242). He then introduced another table, giving the St. Louis death rate per 100,000, covering the period from 1890 to 1893, inclusive, and made some comparisons with similar statistics for Baltimore from 1899 to 1902, inclusive. In discussing these tables he stated that the febrile diseases should all be included

under typhoid, although some of them might have been acute tuberculosis. The addition to the number of deaths from typhoid of those from the febrile diseases mentioned would give, in the opinion of the witness, a truer typhoid rate than any other statistics available. He stated that were the deaths from remittent, intermittent, typhomalarial fevers, etc., examined by skilled clinicians they would be definitely diagnosed as specific diseases. Unless physicians are trained in the most modern methods of diagnosis it is extremely difficult for them to decide between cases of malaria and typhoid. (7091–7094.)

The most important clinical test for typhoid is the Widal reaction or agglutinative test, while that for malaria is the demonstration of the malarial parasite in the blood or tissue of the patient by microscopic observations. (7095.)

The witness then stated that it was absolutely certain that if the statistics presented by the St. Louis health department for typhoid and malarial diseases were reliable, there had been no increase in the typhoid rate. The total deaths from these various causes run along together at a tolerably constant figure. They show in the typhoid-fever column alone a well-marked increase during the years 1900 to 1902, inclusive. They also show a marked diminution in the remittent and intermittent group, and there had evidently been a transfer from the remittent to the typhoid column. This indicates an improvement in the diagnoses of the practitioners and had no significance so far as any possible increase in typhoid was concerned. (7096–7097.)

With reference to the distance over which the infection of typhoid fever had traveled in a stream, the witness stated that if the extreme statement of one investigator were accepted, the distance would be 70 to 75 miles, but that assertion had not met with general acceptance. (7099.)

In his opinion, a typhoid bacillus which had lain in the sediment of a stream for a period in excess of fifty days would be harmless if taken into the human system. The germs of typhoid fever entering Desplaines River from the Chicago drainage canal would not be a menace to the citizens of St. Louis after passing through the rivers intervening between Lockport and the intake tower at Chain of Rocks. He further stated that there was no evidence that would make it seem probable that the sewage and other matter entering Illinois River below Lockport would prolong the life of such disease germs. In his opinion the introduction of the organic matter from the stock yards and distilleries of Peoria would favor the disappearance of these organisms. He then rendered a similar opinion with reference to the specific germs of Asiatic cholera, tetanus, anthrax, and other water-borne diseases. (7100–7102.)

The witness stated that the probable life of typhoid bacilli introduced into the drainage canal was from five to seven days. (7103.)

The death rate from typhoid fever in St. Louis, compared with that for many other American cities, does not indicate the use of an excessively polluted water supply. (7104.)

The important probable sources of infection of the St. Louis water supply, according to the witness, are those places within a mean flow of five to seven days from the Chain of Rocks intake, and the probability of infection from distances requiring more than twelve days would be remote. (7108.)

The cross-examination brought out no important new facts.

VICTOR C. VAUGHAN.

Victor C. Vaughan, called as a witness on behalf of the defendants, stated that he was a physician and teacher in Ann Arbor, Mich., and had been connected with the University of Michigan since 1876. He had graduated from that University in 1875 and received his medical degree there in 1878. He had made a specialty of hygiene and physiology and had studied with Dr. Robert Koch, in the University of Berlin. He was at the time of his testimony serving his third term as a member of the Michigan State board of health and had been called on frequently to examine into epidemics in the State. In 1898 he was appointed by the President of the United States on a special commission, consisting of Maj. Walter Reed, Major Shakespeare, and the witness, to investigate the spread of typhoid fever in military camps. He had investigated typhoid fever in Camps Alger, Fernandina, Jacksonville, Huntsville, Chattanooga, Knoxville, and Meade, and during that experience had examined probably 4,000 or 5,000 cases of typhoid fever. As a member of this commission he had been engaged practically ever since in writing up the statistics and studying the spread of typhoid fever, and had extensive experience both in the laboratory and on the clinical side of the disease. (7313–7315.)

The witness then defined typhoid, malarial, intermittent, remittent, typho-malarial, congestive, and simple continued fevers, and stated that all except the first two were not distinct types of disease and almost without exception should be interpreted in the vital-statistics reports as true typhoid. Reviewing the number of deaths reported from typhoid fever and from the other febrile diseases mentioned in St. Louis from 1890 to 1903, inclusive, he stated that the typhoid rate was undoubtedly too low and the malarial-fever rate too high. His experience had shown that malaria is not a common disease in Missouri or in that section of the country and that death from it is exceedingly rare—so rare, in fact, that it practically does not occur. He based his statement on his investigations in connection with the Army Medical Commission. Missouri sent six regiments to the Spanish-American war in 1898, and a careful study of the records of all these regiments showed that, although in some of them many cases of malarial fever were diagnosed, these were not malarial cases but

typhoid fever. One of these regiments was quartered at Jefferson Barracks, practically a part of St. Louis, until July, 1898. While malaria was frequently reported by the medical officers in charge, more careful examination showed that there were no such cases. The Sixth Missouri regiment developed 286 cases of typhoid fever, from which 19 deaths resulted. This regiment was stationed at Jefferson Barracks until early in August. It then went to Jacksonville, Fla., where the cases were studied by the Medical Commission, and from the records of this and other regiments it was developed that 96 per cent of the cases diagnosed as malaria were true typhoid. In connection with this, the witness stated that he was born and reared in Missouri and returned to that State every year. He knew something of the malarial and typhoid conditions there, and felt convinced that malaria was a rare disease throughout the State and that practically all the reported cases were true typhoid. In connection with such erroneous reports, the witness stated that many of the physicians were honestly misled. Typhoid fever, in its earliest stages, is often a remittent disease; that is, fever persists for a few hours and then the temperature is reduced to normal for a short period. These conditions would easily mislead a physician who was not accustomed to resort to modern diagnostic methods. He further stated that physicians are frequently actuated by policy in pronouncing a disease as malaria when they are certain that it is typhoid, principally for the purpose of allaying the fears of their parents. In no city in the United States are there so many deaths from malarial diseases as are reported from St. Louis, and while some of the cases may not have been typhoid fever, the inclusion of them all in the typhoid rate would not introduce any significant or material errors. (7315–7320.)

The witness then examined the monthly distribution of deaths during the years 1895 to 1903, inclusive, from typhoid fever and from the other malarial diseases noted, and stated that without knowing anything of the local conditions of St. Louis and simply as a student of epidemiology, he would say that the probabilities are that the typhoid fever in St. Louis was due to local causes rather than to any infection of the general water supply. His reason for this was the even distribution of the deaths throughout the months of each year, whereas, in his opinion, an infection of the general water supply would result in explosive outbreaks. (7320–7322.)

Considering the figures resulting from an addition of the deaths reported from typhoid and those reported as being due to malarial diseases, the witness stated that for 1890 to 1899, inclusive, there is a total of 3,708 deaths, equivalent to an average rate per year of 370. In the four years since 1899, or after the opening of the Chicago drainage canal, the total deaths were 1,261, or an average of 315 per year, showing that the rate was greater previous to the opening of the canal than subsequent thereto. He further stated that the situation would

be reversed if the epidemic years of 1892 and 1893 were left out of the first total. Comparing the typhoid-fever rates in St. Louis with those in other cities, notably New York, Minneapolis, Philadelphia, Richmond, Buffalo, Albany, and Cleveland, he called attention to the fact that there had been an increase in all of these cities and that St. Louis had not occupied a different position in this respect from that of many other places. He attributed this to the fact that typhoid fever has been more widely disseminated over the country, having been, in his opinion, spread from the army camps in 1898. (7323–7326.)

That part of Table 1 showing the typhoid death rate per 100,000 in St. Louis was then presented to the witness, who stated that it did not indicate an epidemic of typhoid fever, inasmuch as in such an epidemic the increase ranges from 100 to 400 per cent and sometimes more. The increase shown was such as might be expected to be due to local conditions, especially if wells were getting more and more filthy and were not condemned. (7326–7328.)

The charts presented in the testimony of Professor Mason did not, according to the witness, show any causal relation between typhoid fever in Chicago and that in St. Louis. (7328.)

The witness then stated that he would look for the cause of increased typhoid in St. Louis in the local conditions. It is a wholly erroneous assumption that typhoid is carried altogether by means of drinking water, and in illustration of this he exhibited a chart based on the record of the Fifteenth Minnesota regiment, which was in camp on the fair grounds at St. Paul and at Fort Snelling, Minn. All of the men were supplied with water from a common source, yet some companies remained practically free from typhoid while others were largely affected. The transferrence of the infection was due, in the opinion of the witness, to direct contact from person to person, infection of tents, clothing, bedding, etc. The condition was comparable to that in crowded cities. (7328–7329.)

The witness could see no evidence from the typhoid statistics that the Chicago drainage canal had anything to do with typhoid fever in St. Louis. In the first place, the distribution of the disease in St. Louis is indicative of local contamination and spreading by contact rather than by any general infection of the water. Second, there are certain cities in which the increase in typhoid fever has been more marked than in St. Louis, notably, Buffalo, from which the Chicago drainage has been turned away. (7329.)

The cross-examination brought out no new facts.

WILLIAM S. THAYER.

William S. Thayer, called as a witness in behalf of the defendants, stated that he was a physician graduated from Harvard Medical School in 1889. After graduation he had spent a year as house physician at

the Massachusetts General Hospital, had studied for a year in Berlin and Vienna, and then had taken the position of assistant resident physician in Johns Hopkins Hospital at Baltimore. He was later appointed assistant professor of medicine in the university, had pursued further studies in Europe, and was at the time of testimony one of the physicians in chief at Johns Hopkins Hospital Dispensary and visiting physician at the Union Protestant Infirmary.

The testimony of the witness was mainly corroborative of that given by Professors Dock, Vaughan, and Barker—namely, that the records of deaths from typhoid fever in St Louis do not constitute a satisfactory statement of the case, because the deaths recorded as being due to remittent, intermittent, typho-malarial, and other febrile diseases should be included in the typhoid column, and if such addition were made no increase in typhoid fever in St. Louis would be shown over and above that which might well be accounted for by natural causes and would be comparable with that in other cities; further, that no relation appeared between the fluctuations and typhoid deaths in Chicago and those in St. Louis. (7465–7501.)

JOHN W. HILL.

John W. Hill, a witness called on behalf of the defendants, stated that he was an hydraulic engineer, at that time engaged as chief engineer of the bureau of filtration of Philadelphia, which was conducting the improvement of the water supply of that city by filtration of the water from Delaware and Schuylkill rivers, the sources of public water supply. This work embraced the filtration of 320,000,000 gallons of water per day and a general reorganization of the distribution system, at a total cost of about $26,000,000. The witness stated that he first engaged in the planning and building of waterworks about thirty-two years previous to the date of testimony, and from that time on information concerning the hygienic quality of water supplies had always been an essential part of his work. He had been associated with about 60 such projects, looking either to the general construction or improvement of municipal waterworks. Wherever his engineering association with water-supply development had concerned the question of quality of water, investigations had been made to determine the desirability of available sources. Prior to his Philadelphia engagement his principal work of this kind had been for the city of Cincinnati, where he was chairman of the original board of engineers that made an investigation and furnished the plans on which the present improvements in that city are being constructed. He had also engaged in engineering along Ohio River at Parkersburg, W. Va., and Madisonville and Jeffersonville, Ind., the purpose being to determine the desirability of drawing water from Ohio River for drinking and other domestic purposes. He then gave an extended list of other cities in

which he had made investigations concerning the desirability of streams as sources of public water supply. Aside from purely engineering investigations of drainage basins where rivers or ponds had been the sources of public supply, he had taken up the subject of bacteriology and attempted to qualify himself as an amateur in this line, not with a view of practicing the science as a profession, but to gain information as to the bacteriological condition of water supplies, with which, as an engineer, he would be required to deal. He had also studied the chemistry of water with the same purpose in view. (7502–7505.)

He had investigated typhoid-fever epidemics at Eaton, Ohio, and in the Cumberland Mountain region of Kentucky, both as a part of investtigations looking to the improvement of the water supply of Cincinnati. He had also studied the records of all important typhoid epidemics that had been reported, as well as of certain cholera epidemics in Europe and in this country. (7505–7506.)

The witness professed to have examined and studied the analytical data concerning the waters of Lake Michigan, the Chicago drainage canal, and Desplaines, Illinois, Mississippi, and Missouri rivers, presented in evidence of behalf of the defendants by Professors Jordan, Palmer, Burrill, and Long. He also professed acquaintance with the natural features of the above-named bodies of water so far as they are represented in published documents and in hydrographic maps published by the United States Government and the city of Chicago. He had not made a personal examination of the drainage canal, nor of the Illinois River, except in the region of Peoria, where during 1882 he was employed on the Peoria waterworks. (7506–7507.)

With reference to *Bacillus prodigiosus* and its occurrence, the witness believed he had found it twice in investigations of Ohio River water during 1895 and 1896. He had also made experiments on the longevity of the typhoid bacillus in 1895, working with sterilized and unsterilized Ohio River water. These experiments indicated that the typhoid organism would grow in sterilized water without apparent reduction in virility for sixty days at least. The unsterilized water, however, gave negative results, as he was never able to find the germ after the first inoculation. He ascribed this not to the disappearance of the organism after such inoculation, but to his inability to isolate it in culture media. In connection with the work in Philadelphia he had caused experiments to be made with a view to determining what, if any, influence the amount of chlorine in Delaware River water might have on the longevity of the typhoid organism. Concentrations of chlorine in water varying from 25 to 300 parts per million were used, and the fact was revealed that the amount of salt in Delaware River water had little or no influence on the longevity of either the typhoid or the colon bacillus and that their

life was limited to a period varying from five to eight days under th most favorable conditions. It was also revealed that the colon bacil lus would live longer than the typhoid organism in unsterilize Delaware River water with varying degrees of salt concentration These experiments were made because of the probability of an in crease of chlorine content in the water of the Delaware to 50 part per million at a time when the city of Philadelphia would be drawin 350,000,000 gallons per day for the city supply, the excess of chlorin being due to the influx of tidal water coming up the river from Dela ware Bay. (7508–7510.)

Tables 88 and 89 were then introduced, giving the results of th above investigation. (7512–7513.)

In the opinion of the witness the above experiments afforded dat on which to base an opinion concerning the longevity of the typhoi organism in polluted river water. In the absence of information t the contrary he would assume that the longevity of such organism in lake or river water where sewage pollution was no less than i Delaware River above Philadelphia would be substantially the sam as that found by him in these experiments. He gave this opinio mindful of the fact that the temperature of incubation doubtles would be the same for unsterilized as for sterilized water taken fro any other suspected source of supply. In estimating the longevit of these organisms collected at some other point or from some othe streams or source of water supply he would be governed by th results of the tests made on Delaware and Schuylkill river waters, an he would feel safe in expressing an opinion from such data that th organism would certainly not live longer in unsterilized than it did i sterilized water, and would probably have a shorter life histor He would expect that its life in unsterilized water would certainl be no longer and probably less than eight days. He regarded th conditions of the laboratory tests usually made as more favorabl to the growth or the persistence of the typhoid organism than natura conditions, owing to the fact that a constant temperature is main tained in the flasks in which incubation is carried on and all othe conditions conducive to the preservation of the life of the organism are generally observed. He would estimate the life of the typhoi organism in a sewage-polluted river water as from five to eight days The degree of pollution would have an important effect. He assume as a general proposition that rivers where they are used as sources o public supply, like the Delaware, Schuylkill, Merrimac, Hudson Missouri, or Mississippi, do not differ widely with reference to sewag pollution, which is more intense in some cases and at some point than in others, but nevertheless there is a distinct pollution in al these streams that would have some modifying influence on the lon gevity of the organisms. (7514–7517.)

Date of inoculation of test flasks.	Average temperature during experiment (° F.).		Estimated organic matter introduced into test flasks (parts per million).	Kind of water.	Chlorine added to water (parts per million).	Numbers of *B. typhi abdominalis* per cubic centimeter in test flasks after incubating at given temperatures for periods in days as follows:								Temperature of incubation of plates (° C.).	Number of days of incubation.	Kind of medium.
	Test flasks.	Schuylkill water at entrance to building.				0.	1.	2.	3.	5.	8.	12.	14.			
Oct. 7, 1901	73	64	0.25	Schuylkill River	0	130	120	27	7	0	.....	.....	.....	39	1	Lactose agar.
			.25	Delaware River	0	150	100	12	0	0	.....	.....	.....			
			.25	do	25	150	140	100	55	0	.....	.....	.....			
			.25	do	50	150	65	12	0	0	.....	.....	.....			
			.25	do	75	140	80	6	1	0	.....	.....	.....			
			.25	do	100	150	60	11	1	0	.....	.....	.....			
			.25	do	200	160	75	6	1	0	.....	.....	.....			
			.25	do	300	130	80	26	4	0	.....	.....	.....			
Oct. 16, 1901	63	62	50	Schuylkill River	0	110,000	43,000	25,000	4,200	1,000	3	.....	0	39	1	Do.
			50	Delaware River	0	110,000	38,000	25,000	6,200	1,200	1	0	0			
			50	do	25	110,000	41,000	28,000	8,100	1,800	1	0	0			
			50	do	50	80,000	34,000	22,000	4,900	1,000	1	.....	0			
			50	do	75	85,000	35,000	26,000	7,500	1,700	0	.....	0			
			50	do	100	100,000	36,000	24,000	9,800	2,000	3	.....	0			
			50	do	200	74,000	63,000	27,000	12,000	2,500	4	.....	0			
			50	do	300	62,000	34,000	23,000	2,200	600	0	.....	0			

TABLE 89.—*Results of experiments to determine the longevity of Bacillus coli communis in sterilized raw water of Schuylkill and Delaware rivers under various conditions of chlorine content.*

Date of inoculation of test flasks.	Average temperature during experiment (° F.).		Estimated organic matter introduced into test flasks (parts per million).	Kind of water.	Chlorine added to water (parts per million).	Numbers of *B. coli communis* per cubic centimeter in test flasks after incubating at given temperatures for period in days as follows:								Temperature of incubation of plates (° C.).	Number of days of incubation.	Kind of medium.
	Test flasks.	Schuylkill water at entrance to building.				0.	1.	2.	3.	5.	8.	12.	14.			
Oct. 7, 1901	73	64	0.25	Schuylkill River	0	180	230	1,700	(a)	(b)	(b)	.....	.....	39	1	Lactose agar.
			.25	Delaware River	0	180	140	61	49	.....	15	.....	.....			
			.25	do	25	180	140	16	2	.....	0	.....	.....			
			.25	do	50	160	100	9	4	.....	1	.....	.....			
			.25	do	75	170	120	13	5	.....	2	.....	.....			
			.25	do	100	160	130	22	6	.....	2	.....	.....			
			.25	do	200	200	140	18	3	.....	1	.....	.....			
			.25	do	300	190	180	33	7	.....	2	.....	.....			
Oct. 16, 1901	63	62	50	Schuylkill River	0	41,000	18,000	2,500	2,000	1,400	800	400	400	39	1	Do.
			50	Delaware River	0	35,000	13,000	2,200	350	70	30	11	8			
			50	do	25	61,000	16,000	4,900	1,200	240	120	63	44			
			50	do	50	35,000	15,000	4,300	1,400	650	110	52	37			
			50	do	75	46,000	9,200	2,100	750	300	110	17	19			
			50	do	100	45,000	17,000	6,200	650	300	43	17	8			
			50	do	200	35,000	12,000	1,600	700	80	35	8	2			
			50	do	300	42,000	13,000	4,300	1,400	550	100	55	34			

a Too thick to count.

b Contaminated.

The witness stated that from such information as he had gathered concerning the bacteriological and chemical characteristics of the water of Illinois River, as disclosed by the data presented in evidence, and concerning the physical conditions with reference to slope and slack-water pools in the river at different points, he would not expect a greater longevity of the typhoid organism in Illinois River than he had found to be the case in Schuylkill and Delaware rivers. The dams erected across Illinois River create important opportunities for sedimentation. Each pool acts very much like a sedimentation basin operated on the so-called continuous plan. Flood conditions that take the river out of its channel in many places increase the opportunities for sedimentation, to the advantage of the purity of the water. The witness was certain that 800,000 cubic feet of Lake Michigan water per minute carried into Illinois River through the drainage canal would not so increase the rate of flow as to impede sedimentation to any marked extent. On the other hand, the dilution caused by such influx should mean a purer water in Illinois River, because, first, it would increase self-purification in a mechanical way by increasing the volume of flow and reducing the percentage of pollution; second, it would increase the rate of oxidation by adding to the polluted water a water containing large amounts of dissolved oxygen. The danger of infection to persons drinking polluted water is really diminished by dilution, because the percentage degree of pollution when referred to the total volume of water flowing is reduced. The dilution of the sewage-polluted water would act exactly in the same manner as the dilution of a poison, and if dilution is increased the pollution may finally be reduced to so small an amount as to eliminate all danger. Therefore, the purer water diverted from Lake Michigan into Illinois River should improve the quality of the latter in proportion to the relative volumes. (7517–7522.)

Being asked whether the addition of Lake Michigan water to the sewage of Chicago draining into Illinois River is a detriment or a benefit to the sanitary condition of the river water considered from the standpoint of chemical and bacterial changes, the witness stated that in general a comparison of the data for the four summer months of 1899 and 1900 indicated that the condition of the river below Peoria was better at the latter period. The nitrites decreased and the nitrates increased, showing that self-purification was progressing in greater degree. In giving this answer the witness stated that some account must be taken of the difference in stream flow for the two years, but that although the evidence of Jacob A. Harman shows that the flow was greater for 1900 than for 1899, nevertheless, some of the chemical conditions indicate better purification in 1900, and it does not appear that the addition of the Chicago sewage has injured

the quality of the water below Peoria. Such addition would undoubtedly increase the current and to some extent the time required for sedimentation. Whenever the increased volume is sufficient to overflow the banks it might have the opposite effect, by reason of the large degree of sedimentation that would take place over the bottom lands. The chief factor governing the case is the mean velocity of flow before and after the opening of the canal. Sedimentation and oxidation of organic matter are favored by low surface slope of the channel, and the purification depends on the time and the distance; in two cases where the distances were the same and the time of flow greater for one than for the other, the self-purification would be most extensive in the stream having the slowest flow. (7522–7523.)

The witness then introduced a series of tables showing the variation in bacteria, suspended matter, total solids, oxygen consumed, nitrites, nitrates, and chlorine at various sampling points along the water course for the years 1899 and 1900 and interpreted the tables as showing the following results:

1. An increase in the bacterial content of the water in Illinois River from Havana to Grafton.

2. A decrease in the suspended matter from Wesley to Chain of Rocks at about one-fourth the distance from the Missouri shore.

3. An increase in total solids from Chicago to Grafton.

4. A reduction in total solids from Mississippi River at Grafton to Chain of Rocks at one-fourth the distance from the Missouri shore.

5. An increase in the total solids from the Missouri shore of Mississippi River at Alton to the Missouri shore at the St. Louis waterworks.

6. A reduction of total solids in Missouri River at Fort Bellefontaine.

7. With two exceptions a material reduction in the total oxygen consumed, which in the opinion of the witness is significant as indicating self-purification by natural processes during stream flow past the 32 sampling stations named.

8. An increase in the total oxygen consumed in Sangamon River, but a decrease at all other stations.

The nitrites and nitrates in the witness's opinion are always significant factors in showing changes taking place in the quality of polluted waters. The nitrites should diminish as the water is reduced in sewage pollution and the nitrates should increase. With the exception of four stations—namely, Desplaines River at Joliet, Kankakee River at Bloomington, Illinois River at Morris, and Sangamon River at Chandlerville—the nitrites are largely decreased. With the exception of nine stations—namely, the Illinois and Michigan Canal at Bridgeport, at Lockport, and at La Salle, Desplaines River at Lockport, Fox River at Ottawa, Illinois River at Ottawa, at La Salle, at

Henry, and at Averyville—there is everywhere a marked increase in the nitrates. Therefore, if the witness were applying the information to the work of filtration he would have no hesitation in claiming the same degree of purification by the filters as is here shown in the canal and river. In view of all the data, and particularly those relating to the total oxygen consumed and the nitrates and nitrites, the witness considered that the condition of the water flowing in the stream at Grafton had been improved. Basing his opinion on the technical data collected for the purposes of this investigation he did not think that the sewage of Chicago in its original condition is manifested in the water of Illinois River at Grafton, nor did he think that infected material from the sewers of Chicago would pass down to St. Louis, because of conditions of low water in Missouri River and high water in Illinois River. (7525–7530.)

In the light of the information presented by the experimental work in this case the witness would not expect a typhoid organism introduced into Illinois River through the Chicago drainage canal to pass the entire length of the stream. On the contrary, he would expect it to perish somewhere in transit before it reached Peoria, the evident reduction of organic matter in the river between the point of discharge into the canal and Peoria being the basis of this opinion. (7532.)

Referring to the statement made in the testimony on behalf of the plaintiff that in spite of the fact that the reservoir at Covington, Ky., was sufficiently large to furnish a thirty days' supply for the city, typhoid was prevalent there, the witness said that he did not believe that the conditions would justify such an assumption, because a large part of the people of Covington do business or are otherwise engaged daily in Cincinnati, and investigations of the typhoid-fever rates in Covington, Newport, and Cincinnati from 1890 to 1896 gave satisfactory evidence to his mind that the larger part of the typhoid fever in the Kentucky cities mentioned is chargeable to Cincinnati water. Notwithstanding this the rate in Covington was less than that in Cincinnati, as shown by the following statement of deaths per 100,000 of population:

TABLE 90.—*Typhoid deaths per 100,000 population in Cincinnati and Covington, 1890 to 1896.*

Year.	Cincinnati.	Covington.	Year.	Cincinnati.	Covington.
1890	67	43	1895	36	27
1891	62	45	1896	48	32
1892	40	40			
1893	43	27	Average	49.4	36.3
1894	50	42			

The witness did not believe that all the Covington typhoid was due to Cincinnati water, but asserted that a large part of it undoubtedly did arise from that cause. In Covington a considerable amount of water is obtained from old-fashioned dug wells, many of which are undoubtedly polluted. (7533–7536.)

In the interpretation of typhoid statistics the witness's preference was for the statement of cases based on the unit of 100,000 population rather than on the mortality percentage, the reasons being similar to those cited in connection with testimony previously reported herein (p. 254). (7537.)

The witness stated that the liability of infection of rivers is not so great from rural as from urban populations. In rural pollution the element of time is important, and it had been shown by the experience of numerous cities that such pollution may cause epidemics. (7537–7539.)

From a bacteriological point of view the water of Illinois River at Grafton is decidedly better than that of Missiouri River at Fort Bellefontaine. The same statement may be made if based on the amount of suspended matter, total solids, nitrates, nitrites, and chlorine. (7542.)

The witness then presented a table showing the relative areas of the drainage basins of Illinois River, of the Mississippi above the mouth of the Illinois, and of the Missouri above its confluence with the Mississippi. On the assumption that the mean rainfall would be the same over the combined drainage areas, and all consideration of the flow of the Chicago drainage canal being omitted, of each 100 gallons of water flowing in Mississippi River opposite Chain of Rocks, 75¼ gallons would come from Missouri River, 20⅓ from Mississippi River, and 4⅜ from Illinois River. As a matter of fact, however, the mean rainfall over the Missouri River drainage area is not so great as that over either of the other two basins, and this being considered it is probable that the total flow opposite St. Louis would be 70 per cent Missouri, 20 to 22 per cent Mississippi, and 6 to 7 per cent Illinois water. Carrying out these computations and considering the added flow from the Chicago drainage canal, the witness stated that on the basis of a uniform rainfall over the entire area of the three rivers 20 per cent of the water flowing opposite St. Louis would be from the upper Mississippi, 75½ per cent from the Missouri, 2.96 per cent from the Illinois, and the remaining 1.54 per cent from the Chicago drainage canal. The witness then presented Table 91, including statistics concerning the drainage basins above mentioned and similar data for Delaware and Schuylkill rivers. (7542–7549.)

TABLE 91.—*Statistics concerning the drainage areas of Missouri, upper Mississippi, Illinois, Delaware, and Schuylkill rivers.*

MISSOURI RIVER DRAINAGE BASIN.

	Drainage basin.			Cities.	
	Area (square miles).	Population.	Distance of mouth from St. Louis (miles).	Population.	Distance from St. Louis (miles).
Missouri River (including all tributaries)	520,086	5,120,607			
Jefferson City, Mo				9,664	110
Kansas City, Mo				163,752	264
Leavenworth, Kans				20,735	290
Atchison, Kans				15,722	305
St. Joseph, Mo				102,979	322
Omaha, Nebr				102,555	440
Council Bluffs, Iowa				25,802	441
Sioux City, Iowa				33,111	530
Big Sioux River [a]	10,009	179,090	550		
Yellowstone River [a]	70,119	49,002	1,165		
Platte River	89,742	727,689	422		
Denver				133,859	980
Kansas River	60,436	1,014,772	265		
Kansas City, Kans				51,418	265
Topeka, Kans				33,608	308
Osage River [a]	16,254	531,765	107		

[a] No large cities on this river.

MISSISSIPPI RIVER DRAINAGE BASIN ABOVE ST. LOUIS.

Mississippi River (including all tributaries except Missouri River)	171,698	8,409,676			
Quincy, Ill				36,252	110
Burlington, Iowa				23,201	178
Rock Island, Ill				19,493	241
Davenport, Iowa				35,254	242
Clinton, Iowa				22,698	270
Dubuque, Iowa				36,297	325
La Crosse, Wis				28,895	423
St. Paul, Minn				163,065	545
Minneapolis, Minn				202,718	557
Illinois River	32,081	3,433,845	37		
Peoria, Ill				56,100	162
Ottawa, Ill				10,588	227
Chicago, Ill				1,608,575	357
Rock River	10,231	564,972	241		
Rockford, Ill				31,051	342
Beloit, Wis				10,436	360
Janesville, Wis				13,185	375
Wisconsin River [a]	12,823	326,197	380		
Chippewa River	8,818	167,098	490		
Eau Claire, Wis				17,517	530
Chippewa Falls, Wis				8,094	542
St. Croix River [a]	7,655	128,623	530		
Minnesota River	16,109	396,790	545		
Mankato, Minn				10,599	615
Cedar River [a]	12,657	470,205	200		
Des Moines River	14,025	513,516	140		
Des Moines, Iowa				62,139	283

[a] No large cities on this river.

DELAWARE RIVER DRAINAGE BASIN.

	Drainage basin.		Cities.	
	Area (square miles.)	Population.	Population.	Distance from Trenton (miles).
Delaware River (including all tributaries except Schuylkill River)	9,217	1,430,367		
Easton, Pa			25,238	42.5
Phillipsburg, N. J			10,052	42

TABLE 91.—*Statistics concerning the drainage areas of Missouri, upper Mississippi, I nois, Delaware, and Schuylkill rivers*—Continued.

SCHUYLKILL RIVER DRAINAGE BASIN.

	Drainage basin.		Cities.	
	Area (square miles).	Population.	Population.	Dist...
Schuylkill River (including all tributaries)	2,008	382,192		
Norristown Borough, Pa			22,265	
Reading, Pa			78,961	
Pottsville, Pa			15,710	

If typhoid-fever germs should be found in Mississippi River w at the Chain of Rocks intake, it would be wholly impossible to s from what source they were derived, because there are many l cities in the drainage basins of the three rivers above St. Louis w might contribute such germs to the river. Other things being e it would be more likely that they would come from the nearest p of pollution. (7550–7551.)

With reference to the alleged increase of typhoid fever in St. I subsequent to the opening of the Chicago drainage canal the wi stated that if the typhoid statistics show an increase in the death per unit of population since the opening of the canal, and if the in tigation clearly indicates that there is no other possible sour infection, and if the rate in St. Louis fluctuates synchronously the rate in Chicago, it might be held that such increase coul charged to the flow of sewage in the drainage canal. In other w unless the rate in St. Louis fluctuates with those in Chicago he w be of the opinion that such increase was caused by much n sources of infection, of which there are many above St. Louis. V it can not be positively stated that Chicago sewage might not tribute to this increase, it is equally out of the question to assert a single city out of many discharging sewage into the rivers abov Louis is the sole cause of it. The city of St. Charles, on Mis River, being nearer the St. Louis intake, would constitute a gr menace to the water supply than Chicago or Peoria. The nea of the place of local infection, rather than the size of the place, i chief factor in determining the source of infection. (7554–7556

The witness then described his investigation to determine the p lation living on the three drainage basins above St. Louis. The step was to divide the total population on the basin by its are result being the distribution per square mile. Then the popul of each urban center was divided by the distance of the center the St. Louis intake. The quotients thus obtained were average the total population divided by the sum of the quotients, thus f the center of population. The effect of this was to give a num

value showing the relative probable degree of pollution of the water flowing past St. Louis from each of the respective drainage basins. The next step was to take the mean of all the quotients obtained by dividing the population of the urban centers by the distance of each center from St. Louis, which gave a factor that fixed the probable center of pollution on each drainage basin. A further step along this line was made by adding together the total area of each of the three basins and dividing the area of each by the total to obtain a factor which would show the proportion contributed by each basin to the water flowing in Mississippi River below the confluence of all three streams. The rainfall was then considered. The amount on the Missouri basin as an entirety would be less than that on the Mississippi or the Illinois basin, and this fact would change the proportions obtained by the last-described computation. The results of these calculations were stated as follows:

The distribution of population per square mile is in the Missouri basin 9.94, in the Mississippi basin above Illinois River 43.21, and in the Illinois basin 107; the urban population per square mile of the Missouri basin 2, of the Mississippi basin 9, and of the Illinois basin 72. The result of dividing the population of urban centers containing 4,000 or more people by the distance of such centers from the St. Louis water intake is for the Illinois basin 209.2, for the Mississippi basin 122.47, and for the Missouri basin 106.56. The relation of these numbers to each other indicates inversely the relative value of each stream as a source of water supply with respect to sewage pollution from all sources. That is to say, the Missouri would have the highest value, the Mississippi next, and the Illinois lowest. In these calculations, however, no consideration is given to the flow of water in the stream. If, however, the flow was greatest in Missouri River, which normally would be the most valuable source of supply for St. Louis, and least in Illinois River, which was shown by the above computations to be the least desirable, the unfavorableness of Illinois River would be mitigated. For example, if the flow of Illinois River was 1 per cent of that of Mississippi River in front of St. Louis, then, notwithstanding the fact that the Illinois is the most objectionable drainage basin from which to draw the supply, the effect of this water when compared with the other 99 per cent of water derived from Missouri and upper Mississippi rivers would not be appreciable. (7556–7562.)

The witness stated that it would make no difference either in the cost of construction or the cost of operation of a filtration system at St. Louis whether the sewage of Chicago were turned into Illinois River or not, because from his experince he believed that sewage pollution is not a factor in the cost of filtering a polluted water, but rather that the suspended matter that such water carries would

increase the cost of maintenance by reason of the frequent cl of the beds that such matter would make necessary. The c purification of Missouri River water would be greater than t water from Illinois or upper Mississippi rivers, because the M carries the largest amount of suspended matter. (7563–7566.

No important new relevant facts were brought out on examination.

TESTIMONY IN REBUTTAL FOR PLAINTIFF.

EDWARD W. SAUNDERS.

DIRECT EXAMINATION.

Edward W. Saunders, called as a witness on behalf of t plainant in rebuttal, stated that he had been a physician in practice in St. Louis for twenty-six years, having graduat the medical school of the University of Virginia in 1875. H fied concerning his acquaintance with typhoid fever, and sta the Widal test was used by physicians for the purpose of ma early diagnosis of the disease. He considered that this test general use among the medical profession in St. Louis, a reference to the effects thereof stated that many cases of that had been supposed on clinical diagnosis to be typhoid fe not been supported by this test, the result of which was th had been eliminated from the typhoid list, thereby having dency to reduce the numbers of fatal cases reported since th duction of the method. On the other hand, he was of the that the use of the test had resulted in correcting the diag malaria and placing it under the head of typhoid. On the lower rate of fatality from the disease had been the result adoption of this test. (7587–7593.)

In the witness's opinion the circular sent out by the St board of health urging all physicians to report their cases of fever had had no effect. (7593–7594.)

With reference to various medical terms, he stated, first, had no idea what the term "congestive fever" meant, but i not necessarily be included among typhoid cases; second, understood the term "typho-malaria" as being a complica typhoid fever and malaria; third, he would include "re fever" among the typhoid cases generally, because indigenou tent fevers are not fatal; if, however, the case had been th very young or very old person and death had occurred at th of the disease he would believe it to be malaria, but not if de occurred after a protracted illness, because quinine, usually istered in such cases, is as a rule a specific; fourth, he expres

same opinion concerning "intermittent fever" as above noted with reference to remittent fever; fifth, he had no conception of what the term "bilious fever" meant; sixth, deaths referred to as caused by "simple continued fevers" he would place in the typhoid class, inasmuch as he believed in the dictum of Doctor Osler that any fever that continues a week and is not amenable to quinine must be typhoid. (7594–7596.)

CROSS-EXAMINATION.

On cross-examination the witness admitted that if it should appear in the health statistics of St. Louis during the last ten years that there was a group of deaths reported as remittent, intermittent, typho-malarial, congestive, and simple continued fevers and that these deaths amounted to something like 200 a year, it would be a reflection on the diagnostic ability and carefulness of the doctors making the reports. If the number of deaths from typhoid and the number reported to be caused by the other febrile diseases were about the same, it would be his opinion that the majority of these latter cases belonged in the typhoid column, and in the light of such evidence he would say that the physicians of St. Louis were not employing the Widal test. He admitted it to be the fact that practitioners wedded to old forms of treatment are obstinate in accepting new forms and that this would make itself manifest in the mortality statistics. Assuming that approximately the same number of deaths are recorded from typhoid fever as from the other febrile diseases mentioned, he would conclude that the typhoid report is as inaccurate as the other one, and he attributed these inaccuracies to failure in diagnosis. He further stated that physicians in general practice in St. Louis are not possessed of the degree of skill necessary to make the microscopic diagnosis either of malaria or typhoid. (7600–7605.)

With reference to the comparative fatality of typhoid and malaria, the witness stated that in his entire practice he had never written a death certificate from any form of malarial fever except in the very young, when convulsions carried off the patient in the onset of the disease, or in the aged, where malaria caused the death of a very weak person. (7608.)

WASHINGTON E. FISCHEL.

DIRECT EXAMINATION.

Washington E. Fischel, called as a witness on behalf of the complainant in rebuttal, stated that he had been practicing medicine in St. Louis since 1874. He graduated from the medical department of Washington University and had taken postgraduate studies in the

universities of Berlin and Vienna. He had devoted himself e
to internal medicine, which included the treatment of typhoid
and was at the time of testimony connected with St. Luke's H
and the city hospital, and lectured to classes in the latter.
7613.)

The witness stated that, taking into consideration the value
Widal test in early diagonsis of typhoid fever, and also the fa
typhoid is a disease which, if properly treated in its early st
less likely to become fatal than if diagnosed later, he believed t
introduction of this test would lessen the mortality in St. Lou
further stated that he had observed more typhoid fever dur
winter and spring months within the last few years than fo
but did not recall any circular sent out by the city board o
with reference to reporting cases of typhoid and had heard
cussion of it among the profession. He stated that personall
had no effect on his actions in connection with reporting cas
believed, however, that many cases of deaths from typhoid fe
not been reported as such, for the reason that the physician, i
ing reported the case at its onset, would endeavor to avoid
sibility in the death certificate. With reference to the variou
for febrile diseases noted in the preceding testimony, he stat
he could not define the meaning of "congestive fever," but
would suppose that it might mean typhoid or, on the other
might mean something else. Similarly, deaths reported as ca
remittent or intermittent fevers would not necessarily be t
but might be tuberculosis, pneumonia, meningitis, or dip
(7614–7617.)

He then said that the effect of the opening of the drainag
had been to make him extremely careful with reference to ti
nosis of typhoid, because naturally he felt that there was
danger from the Chicago sewage and he wanted to make it
himself whether in his experience that danger existed, and t
he never reported a case as typhoid when the Widal reaction
positive. (7617–7618.)

CROSS-EXAMINATION.

On cross-examination the witness admitted that the con
his statement concerning the effect of the use of the Widal t
was true, namely, that many deaths from typhoid were rep
being due to other diseases. He was not of the opinion, h
that if the typhoid in St. Louis prior to the opening of the ca
been diagnosed with the same degree of care that had been us
sequent to the opening there would have been a larger nu
deaths reported, because the rule is that the clinical picture of t
is no clearer and positive diagnosis would be made in a maj

cases without the Widal reaction. The deaths reported as being due to remittent, intermittent, and other febrile diseases may have been tuberculosis. He was of the opinion, however, that among these deaths typhoid fever should be reported more often than tuberculosis. He believed that the circular sent out by the board of health after the opening of the drainage canal, calling attention to the necessity for reporting typhoid, had, on the whole, made the physicians more careful. If the official statistics should disclose that the number of typhoid-fever deaths had increased since the opening of the canal and the number of deaths from the other febrile diseases mentioned had decreased, it would be an indication that the physicians had exercised more care in diagnosis. He would assign faulty diagnosis as a reason why many of the deaths were reported under the miscellaneous febrile diseases, and admitted that where it was found that the number of deaths attributed to these causes in a city of the size of St. Louis amounted to about 200 a year it was an indication that there were a great number of physicians who were not abreast with the profession. (7619–7623.)

LUDWIG BREMER, ALBERT E. TAUSSIG, AND C. H. GOODMAN.

Similar testimony in rebuttal was rendered by Drs. Ludwig Bremer, Albert E. Taussig, and C. H. Goodman. Doctor Goodman stated that although he had seen a number of cases of pernicious malaria in St. Louis, he would be greatly surprised if the fatality ran as high as 50 annually.

HERBERT E. SMITH.

DIRECT EXAMINATION.

Herbert E. Smith, a witness called on behalf of the complainant in rebuttal, stated that he was dean of the medical school at Yale University, had studied in the Sheffield Scientific School of Yale University in the chemical and bacteriological courses, and then in the medical department of the university. He received his degree of doctor of medicine at the University of Pennsylvania in 1882. Since graduation he had been connected with the Yale Medical School under various designations, and at the time of testimony held the title of professor of chemistry and dean of the medical faculty. In the eighties he was appointed one of the Connecticut State chemists; was later appointed chemist of the State board of health, and for a period of fourteen years had had immediate charge of all the work, chemical and bacteriological, which the board had done in the matter of river pollution. Since 1887 he had been a student of bacteriology and had imported one of the first sets of Koch's bacteriological apparatus into the United

States. His experience along all the lines of water supply, water lution, and water and sewage purification had been continuous, a had investigated epidemics of typhoid fever throughout the St Connecticut. (7679–7683.)

Tables 86 and 87 (pp. 284,285), introduced into evidence by Pro Kinnicutt for the defense, were exhibited to the witness, also th Professors Long, Palmer, and Jordan. He stated that they di furnish sufficient data to permit him to form a positive opini regard to the value of the drainage canal as a septic tank in the fication of sewage. While the figures show that there is a consid solution of suspended matter and decomposition of organic m and a reduction taking place in various ingredients in the sewage passing through the canal, no opinion could be formed from the cerning the destruction of pathogenic organisms, particularly th typhoid fever. While a reduction might be apparent, there was ing to show how efficient the canal was in this respect. The t concerning the water at the various sampling points in Illinois show the composition of the samples of water at the time and pl which they were collected. Those in the upper portion of the s show a very high chemical and bacterial pollution, and there gradual diminution in the amount of the various constituents the progress down the river to Averyville, an increase below Peor a further reduction to Grafton, but the samples at Grafton sho siderable evidence of sewage contamination still remaining results fail to show, however, the true conditions of the river several stations at all times, because a sample taken from a r stream from time to time can not show the composition of the r that place at other times. The witness further stated that the no evidence in the tables that the samples taken at the time amount proportional to the flow of the river, and obviousl would represent a different proportion of the constituents at ti flood from that which they would in times of low water, inasm the samples were all of the same size. With reference to the ind results on which the averages were based, the witness stated tha were many which deviated widely from the average and tha averages do not show a true condition, because the general a can relate only to conditions at the times when and the places the samples were taken. A sewage-contaminated stream greatly from time to time in its content of impurity, depending on the irregularities in the discharge of the sewage. At one ti sewage will be of a certain character and at another time it wil widely, either because of the varying character of the materi charged from manufacturing plants or because of the differenc are found in the flow of sewage from houses at different parts day. Moreover, there is a very marked difference in the fl

streams, due to the variable rainfall at different seasons and times. This has the effect not only of increasing the volume of the flow, causing a consequent dilution, but also of bringing down accumulated polluting materials in the drainage area. Therefore an average result can not show the condition of the stream at all times. The witness asserted that the tables of averages introduced by Professor Kinnicutt do not form a competent basis in the present condition of sanitary science on which to form a definite opinion as to the sanitary condition of the stream to which they relate. He based this assertion on his belief that chemical analyses do not and can not show all the evidence of dangerous pollution that might exist in a stream. Such analyses are addressed to the detection and determination of certain elements that are useful in demonstrating the presence or absence of sewage in a stream, but in the present state of the science it is impossible to decide whether certain results are or are not evidence of sewage contamination. Furthermore, there are certain ingredients coming from sewage, which may be present in a stream and which are of material importance, that are not revealed by the chemical analysis. In the opinion of the witness neither do the bacterial analyses, in the present state of sanitary science, reveal in all cases the presence of constituents of sewage. (7683–7692.)

The witness had examined the figures relating to the extent of population residing on the drainage area of Illinois River, both urban and rural, the figures showing the amount of sewage discharged into Illinois River at various points along its course, and the data showing the flow of the river. Taking all these into consideration, he was of the opinion that the urban population on the several drainage areas tributary to the Illinois, exclusive of that of the Chicago sanitary district, gives, according to the analytical tables presented in evidence, a greater amount of sewage pollution than he would expect on a river of that size and population, and that such an excess of pollution must come from the Chicago drainage canal. Considering the sources of pollution and the natural and artificial conditions existing along Illinois River previous to the opening of the canal and comparing the same with those which were present subsequent to the opening, he stated that the earlier conditions were such as to afford greater facilities for the removal of pathogenic organisms than had existed later. (7692–7697.)

On the assumption that the sewage of Chicago passes through the drainage canal into Desplaines River, down the Illinois to the Mississippi, and past Chain of Rocks within ten to twenty days from its initial discharge into Chicago River, the witness stated that it was his belief that the water at Chain of Rocks is less valuable for sanitary use than it was before the opening of the drainage canal and that there is a very much greater liability to infection from typhoid fever

of persons drinking the water from that point in the river. The increase of volume of Illinois River by the addition of water from the drainage canal at the rate of 250,000 cubic feet per minute would cause an increase in the flow of Illinois River, and would thereby largely increase the liability of typhoid-fever germs passing down into Mississippi River past Chain of Rocks in a virulent condition and thus becoming a serious menace to the health of persons living below the mouth of the Illinois. (7697–7701.)

A sanitarian in order to enable himself to pass intelligently on the character of a water should avail himself of all knowledge obtainable on the subject. A chemical examination may give such results as would indicate that the water is sewage polluted; but to decide how important the pollution is its condition and extent must be determined as far as possible by other means. There are cases, however, in which the chemical analysis will fail to give positive data as to the presence of pollution even when it is undoubtedly present, as shown by other data. The bacteriological analysis frequently aids in obtaining results indicating the presence of sewage contamination, but in other cases will not disclose the presence of anything of the kind. Such tests have often failed to show evidence of contamination even in streams which were known to have received sewage. In determining whether a water in use has been exposed to sewage pollution, the most positive way of obtaining evidence is by a careful study of the character of the effects which have been produced on the people using such water. Where a large community uses a water which has been sewage polluted and the injurious ingredients still persist, the fact is inevitably shown in its results upon the health of the people. The statistics of typhoid in a community are on the whole the best evidence of sewage pollution. (7701–7702.)

The witness stated it very positively as his opinion that typhoid bacilli living in the sediment of a polluted stream for a period of sixty days would be able to produce typhoid fever if taken into the human system. When typhoid bacilli are deposited on the bottom of Desplaines and Illinois rivers between Chicago and Peoria for a period of thirty or forty days they might retain their dangerous qualities if there is nothing which would make it certain that such organisms would meet with any material which would surely be destructive to them. Under such conditions the discharge of the drainage canal has unquestionably been, in the opinion of the witness, the cause of typhoid fever in St. Louis. (7703–7705.)

With reference to the location of the so-called zone of purification, mentioned in the testimony of several witnesses for the complainant, Professor Smith stated that the conditions affecting the purification of streams were so complex that it would be impossible by the ordi-

nary methods to determine at what point in the river the purification was effected. The only entirely satisfactory way which could be suggested was by a study of the results of the use of such water by communities. If these fail to show any evidence of deleterious effects, it might reasonably be concluded that the point under consideration was outside of the zone of danger during the time of the experiments, but owing to the fact that the chief deleterious constituents of sewage are living organisms and that at certain times they may, by being embedded in solid materials, be protected from influences ordinarily adverse to them in streams it would be impossible to predict with certainty that at some other time than that of the experiments the water would be perfectly safe at that point. It is important to recognize in the matter of sewage pollution that the chief injurious ingredients are living organisms and that the question of dilution does not come into the discussion to anything like the extent that it would if the injurious ingredients were inert chemical substances. If the latter were the case, these ingredients could be diluted to such a point that the dose in any given amount of water in the stream would be without effect on living persons, but it is necessary to recognize that dilution does not affect the individual living organisms but only their dissemination through the water. It is possible, therefore, to find in one portion of the water something that will be deleterious, while in another adjacent portion there may not be any. There are no experiments which are entirely satisfactory in proving that typhoid bacilli are not able to survive in sewage for a period of three or four days or even for longer periods. In view of these facts and the further fact that the bacilli may be deposited in the bottom of a stream under conditions which would protect them from certain deleterious influences, it would be his opinion that typhoid bacilli may survive for a very much longer period than three or four days. (7705–7708.)

The experiments of Professors Russell, Jordan, and Zeit on the longevity of typhoid-fever bacilli, conducted by using parchment sacks, according to the witness, do not exemplify the true conditions found in a stream. The introduction of the typhoid bacilli in an artificial manner in such a quantity of sewage, inclosed in a parchment sack, does not simulate the condition that would exist in the case of typhoid bacilli discharged into sewage and coming from a patient suffering with typhoid fever, in which case the organisms might readily be inclosed in fecal matter. Further, the condition of the bacilli in the sack is quite different from that in which they would be if they were free in the stream, where they could be deposited in the sediment and become protected from the influence of sewage on them. Inclosed in the sacks, the bacilli would be subjected to the frequently

changing condition of water in any one spot, while if not so r they would pass farther down the river and be free from the rious effects of such changes. As they pass downstream, the tions would become more and more favorable to them owing greater dilution and the proportionate decrease of unfavorat stances in the water. The results of the parchment-cell investi do not agree with other experiments that have been made by rians, and he did not know of anyone who had felt justified as of these experiments in limiting the period which typhoid bac survive in sewage. No information was given concerning the matter in the parchment sack; it might have been so far deco as to afford no nutriment to the bacilli and they might have d result, but in general the conditions prevailing in the sack much at variance with the normal conditions and the results at variance with the ordinary experience of persons who have deal with epidemics of typhoid fever that the evidence is alt too incomplete to form the basis of an opinion of so wide reaching importance. (7708–7713.)

With reference to the increased amount of typhoid feve Louis, the witness stated that the absence of any corres increase over the drainage area above Chain of Rocks, excl the sanitary district of Chicago, is sufficient to demonstrate tl increase must have been due, in considerable part, at least, t tion from the Chicago sewage. In making comparisons of co before and after the opening of the canal the competent me deciding whether or not there has been an increase is to comp typhoid rates in St. Louis during the two periods 1896 to 189 sive, and 1900 to 1903, inclusive. This affords the best me testing whether or not the sewage of Chicago was deleteriou health of the people of St. Louis. That there had been such an was shown by the mortality records in the office of the S health commissioner. The increase had been more noticeabl the winter and spring months than during the summer and (7716–7720.)

In the opinion of the witness the use of the Widal test had very materially the reports of deaths from typhoid fever, but a more marked influence in the matter of correct diagnosi milder cases. Boards of health in large cities usually hav lations concerning the reporting of certain diseases and amo typhoid fever is always included. Inasmuch as the circular by the board of health of St. Louis shortly after the openin drainage canal related to the reporting of cases of typhoid fe not at all to the reporting of deaths, there was no reason wl should be any special effect in the mortality reports. (7720–7

The witness then testified to his experience in the oversight of water-filtration plants and the costs which they involved, and gave it as his opinion that the installation and operation of a filtration plant at St. Louis would be more expensive by reason of the discharge of Chicago sewage into Illinois River. (7722–7723.)

CROSS-EXAMINATION.

In reply to questions concerning the witness's contention that samples should be taken of an amount proportional to the flow of the river, he stated that if a stream is flowing 1,000 gallons per minute at one point and a gallon sample is taken therefrom the results of the analysis will not be comparable with those obtained with a sample taken from the stream where it is running 2,000 gallons per minute unless the latter sample is 2 gallons. While the results bear the same relation to the amounts taken, such results will have to be considered in making the average; that is, it will be necessary to give a value for the sample collected when the flow is 2,000 gallons per minute twice as large as for one taken when the flow is 1,000 gallons. Furthermore, in order to get thoroughly representative results the samples must necessarily be taken from weirs—that is, from some sort of a weir arrangement which will give a continuous flow, one portion going into the sample bottle and the other going on down the river. There is no substitute for this. The taking of a sample every week or hour or every five minutes will not truly represent the conditions. No one would, however, be likely to recommend the weir method described, because the value of the results obtained would not be comparable with the difficulties. (7723–7725.)

With reference to the character of Missouri River water as a source of supply, the witness stated that by reason of the numerous points of pollution in the drainage basin, he did not regard it an as ideal water for drinking purposes, but the typhoid-fever statistics in St. Louis from the time the water intake was located at Chain of Rocks to the date of the opening of the Chicago drainage canal compare very favorably with those of other cities in the United States having reasonably good supplies. He might recommend the continued use of the water with the sedimentation basin already installed, but it would be necessary to operate the plant with caution. He admitted that the water was not absolutely safe, but contended that there are very few absolutely safe waters, and even those which have been subjected to filtration could not be included among that class. Under such conditions, the expert is obliged to decide as to the reasonable safety of the water, and while he would hesitate to use it himself or to allow his family to use it, yet in giving an opinion concerning it he would have to recognize that it was reasonably safe and that the average community in

the United States does not expect so high a standard for its requirements as he did in his own practice. This opinion he extended to the water of Mississippi River above Grafton and to that of Illinois River if all the sewage from Chicago were excluded. With regard to absolute safety, he stated that he could conceive of such an ideal condition existing in some drainage areas, but it is so difficult to find a large supply of water that is safe at all times that he would not expect to be able to recommend any such surface supply for a large community. (7736–7743.)

Referring to his testimony concerning the increased cost of filtering the water at Chain of Rocks after the opening of the drainage canal over that which would have been necessary had the canal not been constructed, the witness stated that the chief sanitary advantage of filtering water is to remove infection. The rapidity and the character of filtration and the scientific oversight of the operation of the filter all depend on the relative contamination of the water to be filtered. A water which has a certain amount of contamination would be satisfactorily filtered at a certain rate, but if it received a greater amount of pollution that rate would have to be reduced in order to accomplish the removal of the obnoxious matter with the same degree of thoroughness. Consequently, it would require a larger filter plant to purify the same amount of water. Furthermore, filters are liable to fail in their operation at times, and therefore a filter through which a highly contaminated water is being passed must be operated with greater care. It is not true that the chief cost of establishing and operating a filter from a sanitary standpoint depends on the amount of material in suspension. The question of infection is not, according to the witness, a matter of secondary importance. (7743–7747.)

The witness then repeated his opinion concerning the longevity experiments of Professors Jordan, Russell, and Zeit, namely, that the conditions were so different from those naturally prevailing in polluted water that he did not credit the experiments as being sufficient to permit a judgment concerning the longevity of the typhoid bacillus in polluted rivers. If the sacks had been allowed to float down the stream so protected that they would not have been subjected to the changing water conditions, the results might have been more accurate. Also, in the opinion of the witness it would have been a good plan to have tried sacks of such size as to admit the accumulation of considerable quantities of sediment. While the experiments were unquestionably very carefully performed, their weakness lay in the fact that they did not simulate natural conditions; and, in his opinion, the problem is so difficult and the variations in the conditions are so extreme that he could not conceive how laboratory methods of the character described could afford a satisfactory solution. (7747–7750.)

The witness stated that he had examined the typhoid-fever statistics of St. Louis by consulting two sets of data—those in the reports of the commissioner of health and the records in the mortuary office. There was a marked discrepancy in these data. The terms remittent and intermittent fevers are names applied to malarial infections and are used in statistical work as representing the different manifestations of malaria. The term typho-malaria is in variable usage. In the best usage it is confined to the condition which exists when the patient is suffering from a joint infection by the typhoid and malarial organisms; but it has been used to represent conditions that exhibit what is known as the typhoid state, referring rather to the symptomatology than to the case. The term congestive fever is undoubtedly restricted to the severe form of malarial infection that is manifested by the congestive chill. The term simple continued fever is no longer correctly used and does not represent any specific disorder, but grouped under it there have been unquestionably many low conditions which were characteristic of or characterized by continued fever. Many of them were simply bacterial infection, but not associated necessarily with typhoid or malaria. (7750–7751.)

Fatality from malaria differs greatly in different localities. In the temperate zones it is usually confined to feeble persons—either the extremely young or the extremely old, although of course persons of intermediate ages may succumb to malarial conditions if they are in feeble condition. Doctors undoubtedly confuse typhoid fever with other diseases at times, but this misinterpretation is probably much more frequent among cases that do not result in death than among fatal cases, because when a person dies from typhoid fever the condition is likely to display itself in such a manner that the diagnosis is generally corrected at some time before the death if there was a mistake in the original diagnosis. There are, however, some cases which are never correctly diagnosed. It is not uncommon for a physician after he has improperly treated a patient through faulty diagnosis to change his diagnosis on the occurrence of death when the symptoms become apparent and to record the death on the certificate in conformity to his later diagnosis. The witness had considered the typhoid deaths as reported and the data concerning each of the other febrile diseases. Even if all of the latter were included in the former, there was still an increase in the number of typhoid cases from 1900 to 1903, inclusive, over and above those occurring from 1896 to 1899, inclusive. He had also considered the compilations of deaths from the various febrile diseases with a view of forming an opinion as to whether any considerable portion of them were typhoid, but from the standpoint of the age of the person and the distribution of the cases by months he believed that comparatively few of them should be

included in the typhoid class. The proportion of typhoid deaths due to local causes—such as wells, etc.—in St. Louis could not have been greater since the opening of the canal than previous thereto, and the rate which prevailed during the first period was about the same as that found in some of the cities of the better class in the United States. (7751–7755.)

JOHN W. ALVORD.

DIRECT EXAMINATION.

John W. Alvord, called as a witness on behalf of the complainant in rebuttal, stated that for twenty-four years he had been a practicing hydraulic and sanitary engineer in Chicago; that he had not graduated from any technical institution, but his engineering education had been confined to study and travel, coupled with practical experience. His first engineering work was in 1879, when he was connected with the construction of the Hyde Park pumping station of the Chicago waterworks. Subsequently he was in charge of the construction of the Lakeview station, and for four years was city engineer of Lakeview, which was at that time a separate municipality from Chicago. He had visited Europe in 1888 and 1894 and studied the question of water purification and sewage disposal. From 1890 to 1893 he had charge of a department in the construction of the World's Columbian Exposition. He resumed private practice in 1894 and had since been engaged in various capacities with about 35 different city waterworks and 45 municipal sewer systems, including the purification of water and the disposal sewage. In 1898 he made a report to the city of Columbus, Ohio, on the extension of its sewerage system and the purification of its sewage. From 1898 to 1902 he was consulting engineer to the Illinois State canal commission, advising as to the works of the sanitary district in and through Joliet and the litigation concerning the removal of dams and locks at Joliet. More recently he had been engaged in the development of water power at Petoskey, Mich., Big River, Mo., and Des Moines, Iowa. He had had some experience in typhoid epidemics, having studied them at Chicago in 1892 and 1893; at Hurley, Wis., Ironwood, Mich., Culver Academy, Ind., and Grand Forks, N. Dak., in 1894, and at Duluth in 1896. So far as he had studied these epidemics all of them had been caused by polluted water supplies. He was familiar with Chicago River, the Chicago drainage canal, and Desplaines and Illinois rivers, having in 1888 been engaged in litigation on behalf of the State of Illinois, and he had studied the progress of the construction of the drainage canal and related questions. He had observed Illinois River at Morris, where he designed a system of sewers; at Ottawa, where he was engaged in water-power litigation; at Marseilles, where he advised as to the enlargement of the water power; and at Seneca,

La Salle, Peru, Hennepin, Peoria, Pekin, and Havana. He was also familiar with Mississippi River from Alton to St. Louis. He had given attention to the bacteriology and chemistry of water and had tried to keep himself posted on them in a general way ever since they had come into use among engineers. He had taken a partial course in chemistry at the University of Chicago in 1894, and in 1900 had studied bacterial quantitative analysis under the direction of Professor Novy, of the University of Michigan. He was employed in 1902 by the special commission to investigate the water supply of St. Louis, his part of the work being to study the financial history of the present works—their cost and the cost of operation. In the course of this work he had become familiar with the characteristics of the water-supply system and had visited the sedimentation basins at Chain of Rocks and Bissells Point. He had also made some study of the typhoid conditions on the drainage area above St. Louis, principally, however, from the data submitted in the present case by both complainant and respondents. (7761–7764.)

The witness then introduced a diagram and table showing the relation of typhoid deaths in St. Louis to those on the drainage area above that point. The results are contained in Table 92. (7766.)

TABLE 92.—*Relation of typhoid deaths in St. Louis to those on the drainage areas of Missouri, upper Mississippi, and Illinois rivers.*

Year.	Deaths in St. Louis.	Population in St. Louis.	Deaths in St. Louis per 500,000 population.	Deaths on drainage area.	Deaths in Chicago.	Deaths on drainage area, including Chicago.
1890	277	451,770	307	.....	.....	.....
1891	160	465,000	174	.....	.....	.....
1892	488	477,000	512	.....	.....	.....
1893	215	489,000	220	505	.....	505
1894	178	500,000	178	474	.....	474
1895	106	512,000	103	408	.....	408
1896	106	524,000	101	354	.....	354
1897	125	538,000	116	410	.....	410
1898	95	550,000	86	411	.....	411
1899	130	561,000	116	420	.....	420
1900	168	572,238	147	503	339	842
1901	198	585,000	169	494	509	1,003
1902	222	600,000	185	431	801	1,232
1903	288	612,000	235	.....	.....	.....

This table was then explained by the witness, who made the following statement: In order to determine the causes of typhoid fever the deaths along the different rivers have been separated from each other, so as to determine the source of the most marked pollution. The figures show that the deaths from typhoid in the Illinois basin, exclusive of the sanitary district of Chicago, are fairly uniform up to 1899, but show an increase in 1900, the year in which the drainage canal was opened. The deaths on the Missouri basin appear to be reasonably uniform for the whole period under consideration, and those on the Mississippi basin above the mouth of Illinois River,

while fluctuating somewhat more than the two above described, are generally uniform before and near the time of the increase in deaths in St. Louis. In summing up the total of typhoid deaths on the three drainage areas above St. Louis, it would appear that while there is some fluctuation and a low period about 1896, at no time since the increase in typhoid in St. Louis in 1900 had the number of deaths materially exceeded a fair average rate. The witness observed, however, that the addition of the deaths from the sanitary district almost doubles the total for typhoid in these drainage areas, influencing the pollution of the St. Louis water supply and increasing during 1901 and 1902, so that in the latter year the total typhoid deaths are nearly two and one-half times the deaths on the drainage areas above St. Louis exclusive of the sanitary district. After the opening of the drainage canal there appeared an increase in typhoid in St. Louis, caused undoubtedly by the added typhoid contamination from the sanitary district. (7769–7770.)

The witness stated that he had for some years past considered the longevity of the typhoid organism to be from sixty to ninety days in favorable environments. Although under unfavorable conditions large amounts of these bacilli might be removed from any given source of supply in a comparatively short time, it would not be safe to assume that a water once polluted could be recommended for public use under a period shorter than sixty to ninety days, unless the contamination were eliminated by a carefully designed and operated system of purification. (7771.)

The witness then stated that he was familiar with the experiments of Hiram F. Mills on the longevity of typhoid bacilli recorded in the reports of the Massachusetts State board of health, and also with those of Doctor Horrocks described in the Proceedings of the Sanitary Institute for 1899. He believed that the conditions under which typhoid bacilli are carried away from Chicago approximate those under which Messers. Mills and Horrocks carried on their experimental work. The sewerage system of Chicago has very flat gradients and requires frequent artificial flushing. During heavy rainfalls the entire contents of the sewers are discharged into the river, bringing into it a mass of pollution that has been accumulating for months. Before the opening of the drainage canal such periods of contamination were extremely dangerous to the water supply of Chicago, as shown by the increase in typhoid deaths following them. The heavy flushings of rainfall occur ordinarily in the early spring, after the breaking up of the winter, and at times when the temperature is most favorable to the longevity of the typhoid germs. Such flushing of the Chicago sewer system with its present large proportion of pure water and low temperature furnishes conditions which are more favorable to the longevity of the

typhoid germ than those under which the experimental work of Mills and Horrocks was conducted. The discharge of this amount of pollution furnishes the necessary velocity for rapid conveyance through the sanitary canal and Desplaines and Illinois rivers to the intake of the St. Louis water supply. The increment of comparatively pure water from the tributary streams also increases the dilution and decreases the chances for toxic destruction of the total number of typhoid germs present. As another factor in increasing this rapid conveyance of the pollution the witness stated that in the case of heavy rainfall on the drainage area of Chicago River it is often necessary, in order to prevent outflow into Lake Michigan, to lower the Bear Trap dam at Lockport, so as to produce greater velocity at all stations on the drainage area. This undoubtedly aids in the rate with which the pollution is conveyed away from Chicago and down Illinois River. (7771–7773.)

Referring to the float measurements given in the testimony of Isham Randolph, the witness stated that he was unable to find anything that gives a clue to the amount of discharge in Desplaines and Illinois rivers either at Joliet or Peoria and was therefore unable to determine the stage of the river at the time of these measurements. The experiments were performed in July, 1903, and this time is not covered by the table of discharges in Mr. Randolph's testimony, nor are there any gage readings given at Peoria, although the testimony includes a rating table for this place. The testimony consists of the bare statements that the float passed over the distance in fifteen days, which is raised to eighteen and one-half days by dividing it by eight-tenths. The witness failed to see the pertinency of Mr. Randolph's conclusion that a correction should be made, tending to reduce the maximum surface velocity to the mean velocity of flow. The use of the correction by eight-tenths in the manner described in Mr. Randolph's testimony is a very rough approximation, used by hydraulic engineers when surface floats are run in the most rapid part of the channel of the river in order to determine the average flow for the whole cross section and thus get at the quantity passing a given point at a given time. In the case under consideration, the endeavor is not to determine the quantity of water so passing, but to determine what length of time any given pollution, flowing in mid-channel, will take to pass over the distance from Chicago River to Chain of Rocks at St. Louis. This required, in the opinion of the witness, a determination of the mean velocity of the central section of the stream. The floats described in the testimony were not surface floats but were partly submerged, and gave the mean velocity of the central portion of the stream with a fair degree of accuracy. Therefore the correction, in his opinion, was not necessary and the actual time of fifteen days would fairly represent the total time required for polluted materials

to pass over the distance. With reference to the respective velocities shown by the float experiments of Professor Van Ornum for the complainant and Mr. Randolph for the defendants, the witness stated that in July, 1903, when the work of Mr. Randolph was performed, the water was at a very much lower stage than during Professor Van Ornum's experiments. The latter commenced in a low-stage period between two March rises in the river, when 289,000 cubic feet per minute was flowing over the Bear Trap dam, which gives a very low velocity in the drainage canal. At the same time about 394,000 cubic feet per minute were passing over Dam No. 1 at Joliet. Five days after the operations of Professor Van Ornum were commenced, nearly double this amount was passing over Dam No. 1. It would seem, therefore, that the work was done during a comparatively high stage, but not by any means the highest stage of the river. The observations show that Peoria was passed when the flow of Illinois River was about 50,000 cubic feet per second, which would correspond to a stage of the river somewhat overflowing the banks in the lower courses. As Professor Van Ornum used submerged floats, the witness believed that the actual time traveled represents the mean velocity of the pollution vehicle. He had had occasion to make very careful velocity studies in that part of Desplaines River immediately below the Bear Trap dam and had verified the results of Professor Van Ornum. Summing up the two investigations, the witness stated that nine and eight-tenths days were consumed between Bridgeport and Chain of Rocks, this being based on the mean velocity to Joliet and Professor Van Ornum's results for the rest of the distance. The witness did not consider that this was the shortest time in which pollution could travel the distance. He believed that such high flood stages as occurred in 1892 would reduce the time at least to eight days and possibly to less. He then stated that nine and eight-tenths days represented in his opinion a velocity which could be counted on as occurring during a number of periods each year. (7775–7780.)

The chart introduced into evidence by Rudolph Hering, representing the self-purification of Missouri, Mississippi, and Illinois rivers, based on the longevity of life of the typhoid bacillus as fixed by the experiments made under the direction of Hiram F. Mills, represented, according to the witness, an attempt to derive the possible amount of contamination in the water at Chain of Rocks from the sanitary district of Chicago, by assuming that the original pollution is proportional to the population and that the longevity of the typhoid bacillus is that found by the experiments of Mr. Mills. The chart also makes the same deductions for Mississippi and Missouri rivers. In the case of Illinois River, the length of time of flow from Chicago to Chain of Rocks is taken at eighteen and one-half days, corresponding with the results of Mr. Randolph's experiments. It seemed

to the witness that Mr. Hering had not given due weight to the effectiveness of different populations in the production of pollution. The sanitary district of Chicago has been afflicted for years with an abnormal number of typhoid deaths. The other cities in the Illinois drainage area, deriving their water from artesian wells, have very low typhoid rates. Therefore, it would appear to the witness that to make the chart more exact some method should be introduced by which the disparity in the typhoid data could be allowed for in representing the effect on the St. Louis water supply. The time used by Mr. Hering in the diagram and table (7001–7003) gives the rate of travel of polluting material at low stages of the river, and, therefore, does not fairly indicate the greater danger to the St. Louis supply at medium or high stages. It would seem that the diagram should be so constructed that these modifications would be clearly apparent. The witness then introduced a diagram which he called a schematic representation of the reduction of typhoid bacterial pollution in Illinois River, based on the data and methods proposed by Rudolph Hering in his diagram submitted in the case, but with suggestions for correction, first, by using Professor Van Ornum's float experiments; second, by valuing the effect of contributory population on the basis of a standard typhoid death rate of 20 per 100,000 living; third, by using velocity of pollution vehicle rather than average velocity of cross section of the river. In explaining the diagram the witness stated that the figures cover only the reduction of typhoid bacterial pollution in Illinois River, and are prepared as nearly as possible in the manner introduced by Mr. Hering, based on the experiments of Hiram F. Mills as to the longevity of typhoid germs. The ordinates of the diagram represent the tributary population calculated in its relation to typhoid death production. As a basis for this a standard of 20 deaths per 100,000 living had been assumed, this being the death rate of an ordinarily well regulated city in the situation of Chicago, having due regard to the protection of its water supply. On this basis the witness had determined for the year 1902 the typhoid death rate of Chicago and other places along Illinois River, which are given in the table and accompanying diagram. The population of the sanitary district is taken from Mr. Mills's chart and not from the Federal census. The abscissas of the diagram indicate the number of days consumed in the flow of the pollution from the sewers of Chicago, up to the fifteenth day, based on the float experiments of Professor Van Ornum from Lake Joliet to Chain of Rocks, and on the witness's estimates of the velocity in the drainage canal and Desplaines River down to Peoria. With these data a curve had been plotted, due consideration being given to percentage of reduction in the typhoid contamination from the population center through the proper increments of time, to agree with the experiments of Mr. Mills. This

curve indicates the relative typhoid bacterial pollution so far as it can be predicated on the population. The witness further observed that the chart represented comparative pollution contributed by fatal cases alone. It should be remembered that in fatal cases infection ceases to be contributed to the stream on and after the date of death while in cases not fatal infecting matter may be and is contributed to the stream for days, weeks, and even months. The diagram fails to take into account this extra pollution and therefore must be considered as conservative. On the assumption that the active typhoid contamination is proportional to the population and that the diminution in the number of typhoid germs day by day is as shown in the experiments of Mr. Mills, the modifications introduced into the diagram by the witness would show a considerably increased amount of typhoid pollution entering the intake at St. Louis. Whereas Mr. Hering's diagram shows that the typhoid pollution entering the intake at the end of a low-river flow of eighteen and one-half days is equivalent to an infection from a tributary population immediately above the intake of a city of 13,000 people, the conclusions of the diagram would seem to indicate that the normal flow of fifteen days would be equivalent to an infection from a city with a population of 90,000 located above the intake, having a fatal typhoid rate of 20 per 100,000; while on the basis of ordinary spring floods such as were gaged by Professor Van Ornum, the infection similarly arising at Chain of Rocks would be equivalent to that derived from the population of a city of 415,000, with a death rate of 20 per 100,000. With a maximum flood such as occurs only at infrequent intervals, it would appear that the comparative pollution reaching the St. Louis intake would be equivalent to the infection from a population of 960,000 with a similar typhoid death rate. The witness stated that he used the rate of 20 per 100,000 because there are a very considerable number of cities which have so exercised care and discretion in the protection of their water supplies that they have reduced the typhoid rate to a point lower than that. It would therefore seem to be fairly reasonable to assume that all cities having regard for the purity of their supplies would be able in the light of present science, to reduce their typhoid death rates to this figure, or even materially lower. (7780–7787.)

In the opinion of the witness, the chemical data introduced by the defendants with reference to the character of the contents of the drainage canal do not indicate that any septic action has taken place. The amount of improvement in the sewage in its travel through the canal he believed to be largely due to aerobic action, although possibly there might be anaerobic action to a very limited extent, but not enough to influence the results perceptibly. The dilution of the sewage of Chicago by the richly oxygenated water of Lake Michigan is not a

useful preliminary to septic action, but, on the contrary, is distinctly opposed to the inception of such action. In good practice, it is the endeavor to design a septic tank so as to bring the sewage in as quietly as possible, undiluted with surface or underground waters containing dissolved oxygen. The absence of marked current, the presence in certain places of more foul products and considerable surface scum, the absence of undissolved oxygen as shown by chemical examinations, and the physical production of gases bubbling up through the depths characterize the action of the septic tank in the active reduction of its organic matter. It was the belief of the witness that typhoid germs could survive materially longer under the present conditions of dilution in the Chicago drainage canal than under those which formerly prevailed in the Illinois and Michigan Canal and South Branch of Chicago River. (7787–7791.)

The witness thought that the discharge of sewage from the canal would make more costly the construction and operation of a water-purification system for St. Louis, because such a plant dealing with a seriously polluted water, especially one of known high typhoid pollution, should be more complete and delicately adjusted to its work than one dealing only with a water of rare infection and presenting less dangerous difficulties, such as turbidity and color. The added protection necessary should be in the form of double filtration or complete sedimentation followed by careful filtration. Such double filtration had been resorted to in several places in Germany and had been recommended for Springfield, Mass., and introduced into the filtration system at Philadelphia. (7791–7792.)

The witness was then asked whether in his opinion there was any practical modification of the existing system of sewage disposal in Chicago by which the drainage canal could still be employed for keeping the Chicago River in an inoffensive condition and yet the pouring of unpurified sewage into Desplaines and Illinois rivers could be avoided. In reply he stated that such a scheme would be entirely practicable, and he would suggest, as the proper remedy, the construction of suitable intercepting sewers along Chicago River and its branches, by means of which the sewage flow of the city may be kept out of the river and led along its banks to the upper end of the drainage canal below Bridgeport, and then raised by pumping to a suitable purification plant constructed in accordance with the latest bacteriological principles, and capable of effectually removing from the sewage practically all of its wastes and pathogenic bacteria. The effluent from such a plant could be emptied into the drainage canal near Bridgeport. He had considered the expense in a general way and was of the opinion that such intercepting sewers and purification plant could be constructed at a cost no greater than that necessary to

widen South Branch of Chicago River, as had been done, and he was further of the opinion that the operating expense of such a plant would be no greater than that of the present system of pumping sewage and the necessary dilution water for the northern and southern portions of the sanitary district.

CROSS-EXAMINATION.

The witness had estimated that the cost of such an intercepting sewerage system, the construction of pumps, and the installation of pumping machinery as described by him would be between $12,000,00 and $15,000,000. The plans contemplated the purification of the sewage of the entire sanitary district. He had given detailed consideration to the proper method of sewage purification. He believed that land might be secured at some suitable point for a reasonable sum. At the time the original recommendation was made by the engineering commission for the construction of the canal, sewage purification was not so well developed as at the present time, and there was little to justify the commission in considering such a plan. (7796–7802.)

The witness said he had not compared the typhoid conditions in Chicago and St. Louis by months, in the manner indicated by the charts of Professor Mason, because he believed that it would throw no light on the main question, owing to the many fluctuations and variable elements involved; he would prefer to take the averages for a year, which would show in a more marked manner any main distinguishing characteristics. (7805.)

While the city of St. Charles, on Missouri River, undoubtedly had some effect on the typhoid death rate of St. Louis, there was, in his opinion, no reason to believe that the effect had been greater since the opening of the drainage canal, and therefore the increase that had occurred in the St. Louis death rate could not be accounted for in that way. The witness stated that he did not regard the water from Missouri River at its mouth, from Mississippi River above Grafton, or from Illinois River, even though the sewage of Chicago were excluded, as fit for domestic consumption in the raw state. (7806–7809.)

The greatest item of expense in constructing a filter depends on the kind of water and its amount of pollution. With a turbid water free from typhoid pollution the turbidity will undoubtedly be the cause of the greatest expense, whereas with a water comparatively clear but subject to typhoid infection the infection will be the cause of the greatest expense. In providing filtration for Illinois River at Grafton the purification of the water from typhoid infection would be at least equal in cost to the removal of turbidity, while for the Mississippi the cost would be greater for turbidity and less for typhoid infection.

The witness stated that he disagreed with John W. Hill in his assertion that in the construction of the Philadelphia plant the infection of the water was no element of cost in the operation and installation. (7814–7816.)

E. E. LOCHRIDGE.

DIRECT EXAMINATION.

E. E. Lochridge, called as a witness on behalf of the complainant in rebuttal, stated that he had graduated from Beloit College with the degree of bachelor of science in 1898, having given particular attention to the study of chemistry. During his senior year he had acted as private assistant to Prof. E. G. Smith and had studied questions of water supply. Immediately after graduation he had served as instructor in chemistry for two terms at Drury College, Springfield, Mo. He then returned to Beloit as regular instructor in chemistry, and in 1900 took the regular and some special courses in bacteriology under Prof. E. O. Jordan, of the University of Chicago. He then resumed his studies as private assistant with Professor Smith, and in the course of this work had had occasion to visit many public and private water supplies and to study and investigate several epidemics of typhoid fever, among which were those at Rock Island, Ill., and Baraboo and Ashland, Wis. He had studied the operation of filters for municipalities in a practical way in nine different places. During 1902 and 1904 he attended the Massachusetts Institute of Technology as a graduate student, taking the regular courses in sanitary engineering. In June, 1903, he was appointed by a commission, consisting of George W. Fuller and Samuel M. Gray, to make special studies on the problem of the purification of the water supply of Springfield, Mass. This work involved experimental investigation of various means of double filtration. (7821–7823.)

The witness asserted that he had examined the tables of typhoid statistics introduced into the record and testimony of Doctor Barker and stated that these statistics differ only slightly from the results obtained by compiling the deaths attributable to typhoid fever in the record books of the mortuary office. He did not believe that a comparison of the typhoid-fever deaths previous to 1896 with those subsequent to that year would be practical as a means of determining whether or not typhoid fever had increased in St. Louis after the opening of the Chicago drainage canal, because previous to 1896 the intake of the St. Louis waterworks was so located as to expose the supply to infection from the city sewers, and for that reason it was removed farther up the Mississippi, above such contamination. In order to show the great change in the typhoid-fever mortality of St. Louis at the time the intake was removed, the witness presented a diagram, which appears on page 7825 of the record. In the interpretation of this diagram the

witness pointed out that the death rate from typhoid fever in St. Louis was uniformly high up to the time of the change of the intake from Bissell's Point to Chain of Rocks. Following this change there was a period of five years in which the rate was much lower. In 1900 there was a considerable increase, which had continued through subsequent years to the end of 1903. (7823–7826.)

The subsequent testimony of the witness was addressed to several series of charts showing the occurrence of typhoid fever, malaria, and the other febrile diseases already noted in connection with the testimony of various medical experts of the defense, together with the distribution of those cases according to the sanitary districts of the city. These charts will not be introduced in this digest, but will be explained and discussed so far as practicable. (The reader is referred to the record, pages 7827–7928, for the illustrations.)

The witness introduced six charts showing the occurrence and monthly distribution during 1896 to 1903, inclusive, of deaths in St. Louis from typhoid, remittent, intermittent, typho-malarial, congestive, and the continued fevers. The totals by years from these diseases are shown in Table 93.

TABLE 93.—*Deaths from typhoid and other fevers in St. Louis, 1896–1903.*

	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903
Typhoid fever	102	114	90	121	154	181	216	281
Remittent fever	40	29	26	15	15	23	17	17
Intermittent fever	12	12	16	25	10	12	9	11
Typho-malarial fever	50	42	30	31	36	23	34	36
Congestive fever	26	22	13	15	15	4	15	7
Continued fever	1	1	0	0	1	0	1	2
Malarial fever	27	34	23	35	40	28	38	53
Bilious fever	11	8	3	6	3	5	7	7
Enteric fever	0	1	3	2	2	2	2	0
Typhoid pneumonia	13	18	17	14	9	18	15	26
Typhoid complications[a]	0	1	1	1	0	2	3	8

[a] Not included under other tables.

In discussing the above results the witness stated that the figures did not correspond with the results introduced into testimony by Professors Barker and Jordan. Adding together the figures given in the records of the St. Louis mortuary office for deaths from remittent, intermittent, typho-malarial, congestive, and continued fevers he found that for 1896 to 1899, inclusive, there were respectively 129, 106, 85, and 86 deaths, and if the number of deaths from malaria are added to these the totals for 1896 to 1899, inclusive, would be 156, 140, 108, and 121 deaths, respectively, while Professor Jordan's data give for the corresponding years 177, 172, 134, and 148 deaths—a somewhat greater rate than appeared from the witness's investigations. In contrast to this, he stated that during the period 1900 to 1903, inclusive, he had found for the diseases above-mentioned records showing a somewhat higher rate than that given by Professor Jordan; or, in a summary of both periods, in view of the fact that

malarial fevers were probably recorded in Professor Jordan's list, as they did not occur under another caption so far as the witness could discover, the Jordan list differed from the Lochridge list as follows: Twenty-one more deaths in 1896, 32 more in 1897, 26 more in 1898, 27 more in 1899, 25 less in 1900, 10 less in 1901, 12 less in 1902, and 35 less in 1903, making it apparent, according to the witness, that the reduction in the recorded number of deaths from these diseases during the successive years in the period had not been so great as it had been made to appear by the mortality tables of Professors Jordan and Barker. The witness then presented a series of charts designated as charts 15 to 22, inclusive, showing the deaths from typhoid fever distributed according to sanitary districts and according to whether the deaths occurred in residences or hospitals; if in hospitals and the residence was known, the deaths were referred to the district from which the patient was transferred. (These charts appear on pages 7845–7852 of the record.) With reference to the evidence shown by them the witness stated that there were 40 typhoid deaths in the hospitals of St. Louis during 1896, 21 of which it was impossible to transfer to the proper residence districts; in 1897 20 of the 35 hospital deaths could not be so referred, in 1898 16 of the 26 deaths, and in 1899 11 of the 21 deaths; while in 1900 but 4 of the 35 deaths could not be so referred, in 1901 5 of the 55, in 1902 6 of the 67, and in 1903 3 of the 75 deaths. The charts showed that since 1900 the distribution throughout the seven sanitary districts had been very uniform and that in no district was there an unusual number of deaths when compared to those in the other districts. Such uniformity indicated that the cause of typhoid fever was one equally applicable to all the citizens who use a polluted water supply.

Similar charts were introduced by the witness showing the deaths from malaria for the period 1896 to 1903, inclusive. (See pages 7856–7863 of the record.) The witness stated that these charts indicate the distribution throughout the year and the increase in malaria between 1896 and 1903. The distribution is not so uniform in the city as was shown by the charts for typhoid fever. Similar charts concerning the deaths from typho-malaria elicited the same comment with reference to distribution.

The witness then introduced a series of charts numbered 39 to 46, inclusive, showing the typhoid-fever deaths in St. Louis for 1896 to 1903, inclusive, classified by ages of decedents and month of the year in which the deaths occurred. (See pages 7874–7881 of the record.) From a study of the charts the witness stated that a large proportion of the deaths occurred between the ages of 11 and 50 and that the ages between 6 and 60 will include practically all of them. The number of children under six months of age dying from typhoid is the same during the first four years as during the last four. The charts

showed not only the increase in the number of typhoid cases since the opening of the drainage canal, but also the increase under each age and by the season of the year. He pointed out that there was considerable increase in the winter months, as well as a somewhat less, though marked increase, in the summer months. Previous to the opening of the canal the number of deaths during the period from January to May and the month of December is low, while since the opening of the canal there had been a very marked increase in the number of deaths for this period—much greater in proportion than during the other six months.

The witness then introduced a series of charts similar to the last, giving the distribution of deaths from remittent fever during the period 1896 to 1903, inclusive, also similar charts for intermittent fever. (These appear on pages 7884–7901 of the record.) With reference to the monthly distribution of deaths from intermittent fever the witness pointed out that in 1899 there were 5 deaths from this disease of children under six months of age and 5 more between the age of six months and one year. With this exception the distribution is practically the same in all the charts. There were 17 deaths during 1899 from intermittent fever of persons either below the age of 3 years or above the age of 61, the very young or advanced ages during which persons are not susceptible to typhoid, and only 8 of the age during which typhoid fever is most prevalent. There was not a single death from intermittent fever during 1899 of a patient between the ages of 11 and 30 years, the most fatal typhoid period.

The witness then introduced charts numbered 63 to 70, inclusive, showing by months and ages the distribution of deaths in St. Louis from typho-malarial diseases for 1896 to 1903, inclusive, also similar charts for malaria and malarial fever. These charts appear in the record, pages 7904–7920. The witness stated that they show a decided increase in these diseases since the year 1900 in the ages from about 20 to 40. Similar charts showing the number of deaths from congestive, billious, and enteric fevers appear on pages 7922–7928 of the record.

In connection with the results shown by the charts above described the witness stated that in the earlier years, notably the first four years, 1896 to 1899, inclusive, a much larger proportion of deaths occurred between the months of July and November, but during the years 1901 to 1903, inclusive, there is a decided increase in the number of deaths occurring from December to May and this is greater than the proportional increase throughout the year, so that during the latter period the typhoid-fever deaths are scattered fairly uniformly throughout the year, there being but a few more deaths in the summer and fall than in the winter months. Two charts were introduced to show this relation, the salient results of which are given in Table 94.

TABLE 94.—*Typhoid rates per 100,000 inhabitants in St. Louis, 1896–1903.*

	1896.	1897.	1898.	1899.	1900.	1901.	1902.	1903.
Winter typhoid	9.2	13.9	13.1	15.7	18.8	19.0	28.8	35.2
Summer typhoid	29.5	28.8	19.7	27.8	34.8	42.4	42.8	55.6

The above results were summed up by the witness in another diagram showing an increase in the number of typhoid deaths during the cold months of 1900 to 1903, inclusive, of 118.2 per cent over the period from 1896 to 1899, inclusive; expressed as deaths per 100,000 the increase is 94.8 per cent. Similar calculations with reference to the typhoid deaths during the warm months showed an increase in the number of deaths 84 per cent and in the deaths per 100,000 of 65.7 per cent, making, according to the witness, a total increase after the opening of the drainage canal of 95 per cent in the number of deaths and 77.7 per cent in the rate per 100,000. The data for these results were taken from the records of the mortuary office of St. Louis, and the estimates of population used were the same as those computed by Professors Barker and Jordan and used in their testimony. (7930–7938.)

The witness then took up the consideration of the ages of decedents from the various febrile diseases noted, for the purpose of showing that in the majority of cases these ages were either below or above the periods at which typhoid is generally fatal. He stated that in 1896, for example, the typhoid deaths lie well between the ages of 6 and 60, while over 50 per cent of the remittent-fever deaths in the same year involved either younger or older persons than these age limits. In 1897 there were 11 less deaths from remittent fever than in 1896, but that loss might be considered as entirely among the very young children and it can be seen by referring to the typhoid deaths for that year that not one of these had been added to the column for typhoid fever; in other words, no transfer could have been made to typhoid fever by reason of better diagnosis. If a change in the annual number of remittent-fever deaths had been due to better diagnosis, such deaths had been referred to some other disease than typhoid fever. The study of the table through all the following years for remittent fever will show, according to the witness, this same variation, confined to the number dying under the age of 6 years, the number of deaths during the ages in which the mass of typhoid fever deaths occur remaining practically the same. (7942–7943.)

With reference to deaths from intermittent fever the witness stated that in each of the years 1896 and 1897 there were 12 deaths, but these were in different ages, the same variation in the number of deaths in children under the age of 1 and, in some cases, under the age of 6 being very apparent. He also stated that this might be noticed effectively in the increase of the number of deaths from intermittent fever in 1899

to 25, such increase being entirely in the younger ages. In 19
deaths of persons of 20 years of age and under from intermittent
numbered only 3, while in the deaths from typhoid fever ther
marked increase in this age and no deaths from typhoid were re
in that year under the age of 1, so that the decrease in the num
intermittent-fever deaths in the year 1899 had not been b
about by the transfer of these deaths to the typhoid group.
other age periods the intermittent and typhoid fever deaths ar
tically the same. (7943.)

The witness then stated that the number of deaths recor
being due to typho-malaria was practically the same during t
years before and the four years after the opening of the Chicag
age canal. In malaria there had been a marked increase dur
past few years, and he noted that there were about the same n
of deaths in the younger ages from malaria and malarial fever
these years, but the number among the older people is proporti
higher than the mortality in these ages from typhoid fever.

Referring to the relation between the deaths from congesti
and those from typhoid, the witness noted a large variation
ring among those under the ages of 6 months and 1, 2, and
the variation being about the same as in the case of remitt
intermittent fevers. In 1896, 13 of the congestive-fever deat
under the age of 5 years and 10 of these were under 1 year.
the exception of two years when the congestive-fever list was
variation was due to deaths at these early periods of life and
the aged, the periods during which typhoid fever is not li
attack. The reports for bilious fever showed that in all cas
was no variation in the number. The deaths were at the you
the older age period and there had been no increase in the t
fever deaths in these ages to correspond with the decline in
fever. (7945.)

In reply to a question as to the effect of the Louisiana P
Exposition on the typhoid rate in St. Louis, the witness stat
the highest fatality from typhoid fever per 100,000 populatio
of the four years prior to January 1, 1900, was in 1899, when
was 21.6. This includes the localized epidemic of that year.
assumption that the influx of those connected with the e
tion of the exposition or the attendance thereon would incre
typhoid rate of the city, the witness had calculated the po
that would be required to make 21.6 the death rate per 100
each of the six years since that time. In 1900 there were 154
from typhoid fever in the city. This would indicate a popul
714,000, or an increase of 139,000 over the population of the
1899. Under the same death rate the total of 216 deaths fr
cause in 1902 would indicate a population of 1,000,000, and

deaths in 1903 would require a population of 1,300,000, or an increase of more than the entire population of the city. Therefore, on the basis of Professor Jordan's estimate of the population of the city, which was 618,500 in 1903, or something less than 60,000 increase over that in 1899, it will be seen that the increase in typhoid fever has been much more rapid and can not be ascribed, to any considerable extent, to the addition of cases brought in by visitors during the fair. The witness then discussed the relation of typhoid to population in another way. Considering the figures given by Professor Jordan for the population of St. Louis, and supposing that the typhoid rate had remained 21.6, he stated that this population would have indicated about 130 deaths from typhoid in 1903, while the actual number was 281. Thus it can be seen that the typhoid rate was in 1903 more than double what it was in 1899, while the population increased but a little over 10 per cent. (7945–7947.)

It was the witness's opinion that the conditions under which the experiments of Professors Zeit, Jordan, and Russell with reference to the longevity of the typhoid germ in polluted water were performed did not simulate natural conditions for the following reasons: Any sack lodged at one place will, if the osmotic conditions are as perfect as is supposed, receive the influence of sewage which is constantly fresher than that which would be in contact with the sack should the same be passing downstream. The results, to some extent, vary from earlier results obtained by various bacteriologists. In but three of Professor Jordan's experiments in the drainage canal was the typhoid organism found at all after ten minutes had elapsed. Of these three, one is a recorded instance of its occurrence on the tenth day, which was attributed by Professor Jordan to the fact that bacteria, and especially the typhoid bacteria, may be dried against the neck or some part of the sack, and thus be subject to conditions favoring greater longevity. This the witness accepted as a possible explanation, but suggested another. It is a fact that if several forms of micro-organisms are in the water one of these forms will apparently mask others, as in the case of experiments with *Bacillus coli* and streptococci. In the earlier periods the former mask the latter so well that but few or none are seen, while later the streptococci develop much more abundantly and to an extent overgrow the coli. Later, however, the coli may again appear. In view of this principle, it may have been impossible in any of the earlier determinations of Professor Jordan to have detected the typhoid organism, although there is no conclusive proof that they were of necessity absent up to the time of this appearance on the tenth day, and the three typhoid colonies found may be ascribed to the fact that their presence was masked before that date. The other determinations of Professor Jordan, showing that the typhoid was certainly alive in two cases

different had the work continued throughout the year or de
at some other season than that which was selected. (79

The evidence presented by Professors Jordan and Bu
colon tests, according to the witness, did not by any me
total elimination of the *B. coli* in the waters of Illinois
granted that there was a reduction, but no point was
which there was an elimination. These colon determi
always subject to a great many conditions that frequent
bacilli, so that no reaction of them is given. In a river
quently happens that of two samples of equal volume tak
same source at the same time one will give the positive a
the negative reaction for coli, so that a negative reacti
means an indication of the absence of the germ. (7949-

The witness testified to his familiarity with the Wid
stated that he had frequently made it in the laboratory an
occasions in the office of the city board of health. He did
that the introduction of the Widal test had made any mat
in the reports of typhoid mortality. There are some
believing that it has reduced the number of deaths, becau
in an early diagnosis, which eliminates many cases of
with similar symptoms. (7950.)

CROSS-EXAMINATION.

No new facts were brought out under cross-examinatio
sel for the defense made an argument in support of the rej

official reports of the health commissioner of St. Louis, and if such reports were incorrect and unreliable it was the duty of the complainant to make such proof in chief and not wait until the defendants had rested their case to introduce testimony of impeachment.

WILLIAM THOMPSON SEDGWICK.

William Thompson Sedgwick, recalled as a witness in rebuttal by the complainant, presented evidence concerning the correctness of deductions drawn from the statements of typhoid-fever deaths as percentages of total deaths. The percentage mortality method eliminates altogether from the problem the question of population, and inasmuch as the population in many communities, especially between census years, is a most uncertain matter the value of the method is apparent. On the other hand, there is no doubt that under certain circumstances the method of stating the number of deaths as the rate per 100,000 furnishes more instructive and more accurate results. This is particularly true when the population is accurately known. In order to show that in the case of St. Louis it was immaterial whether the typhoid-fatality rate was stated according to the one method or the other, the witness presented two charts, the first showing the typhoid fatality in that city according to the number of deaths per 100,000, and the second according to the percentage method. The marked similarity in the two curves led the witness to state that no misleading conclusion could be drawn from his original testimony, because either method would show the same essential facts. (7955–7959.)

With reference to the statement in the testimony of Professor Jordan that the witness had incorrectly quoted the report of the rivers, pollution commission of Great Britain, he read from the original report as follows: "There is no river in the United Kingdom long enough to secure the oxidation and destruction of any sewage which may be discharged into it, even at its source." The witness said that the popular version of this statement is that "there is no river in the United Kingdom long enough to purify itself," and he believed that this statement would substantially represent the doctrine of sanitary science at the time of testimony. (7959–7960.)

The parchment and colloidin sack experiments of Professors Jordan, Russell, and Zeit on the longevity of typhoid bacteria when immersed in sewage-polluted water were then discussed by the witness, who stated that he would not be able either to form or to formulate a comprehensive opinion from them. They show that the germs survive for certain lengths of time, but he would be unable to conclude that under different conditions they might not survive for longer periods. In other words, the experiments were by no means conclusive on the longevity of typhoid-fever germs. He stated that he

did not see how it is possible in the present state of bacteriology to devise any series of experiments that would accurately imitate the infinitely varying conditions of running streams. The experiments were carried on in cold weather, but even if they had been continued over an entire year under all actual variations, they would still, in his judgment, have been incomplete for the reason that in other years under other conditions organisms as sensitive as the typhoid-fever germs might have encountered environments that would have materially altered the results. Besides this, the experiments, to speak broadly, indicate a considerably shorter period of life than has been found by the majority of previous investigators. A greater number of experiments conducted for a longer period of time and under different conditions would not, in his opinion, fail to show that typhoid-fever germs live for a very much longer time than was indicated by the experiments under discussion. They were undoubtedly well planned and executed, but it was easy to suggest a great number of points in which they had failed. The fact that the cells were anchored instead of being allowed to float down the stream was important. It can readily be seen that this is an unnatural condition, especially in the case of the Chicago drainage canal and Illinois River, for the reason that the chemical composition of these bodies of sewage and water is subject to frequent changes. If, for example, the waste from a large industrial plant should be turned into Chicago River at any particular moment, the water which received it would vary materially in chemical composition from that just preceding or just following. Again, the seasonal variations must be taken into consideration. The floods in the tributaries bring in new materials and new bacterial flora. The principal trouble was, in the opinion of the witness, that in trying to fix the longevity of typhoid-fever or any other microbes it is necessary to deal with extremely sensitive and almost infinitesimal organisms which have been known at all only within the last few years and which are not yet by any means thoroughly known. (7960–7963.)

He then referred to the testimony and charts introduced by Professor Mason in which it was asserted that there was no relation between the number of deaths from typhoid in Chicago and the number in St. Louis, and stated that, taking into consideration the distance between the two cities and the time required for the passage from Chicago to St. Louis and taking into consideration also the character of the drainage canal and Illinois River and the fact that the water drawn from the intake at Chain of Rocks for public supply is subjected to extensive sedimentation, he would not expect to find any close correspondence between the typhoid-fever curves of the two cities. Consideration must also be given to the fact referred to by Professor Zeit in his testimony, namely, that typhoid germs arriving

t act through the formation of local foci of infection, d for which must always be of uncertain duration. t to find a correspondence between the prevalence of the two cities only when considerable periods were is, of course, probable that a very severe epidemic of cago would make itself felt in St. Louis in such a way d effect would be obvious, but here again much would season of the year, the rate of flow, local conditions of the efficiency of sedimentation in the St. Louis basins. ve, however, that by taking long periods and averages ions were apparent, for example, as when comparing the oid-fever deaths previous to 1900 with the rate for the ing. (7963–7964.)

ess also expressed doubts concerning the significance of acillus tests made with the water of Illinois River by Prolan and Burrill. While these do show a very great decline ber of organisms present in the lower reaches of the river e when the experiments were performed and in those parnples, they do not in any sense enable one to form a correct the presence or absence of typhoid germs in the water at nts. Only a comparatively small number of specimens were l, and from the nature of the case such specimens only imperpresent the true and complete character of the stream at all l seasons; moreover, the colon test is by no means a sure and neasure of the presence or absence of either the colon or the bacillus. He was of the opinion, therefore, that while the Professors Jordan and Burrill throws great light on the proccterial purification going on in Illinois River, it does not by ns establish the fact that typhoid infection is completely or y removed from the water of the river before it empties into issippi at Grafton. (7965–7966.)

itness stated that he was thoroughly familiar with the tables ed by E. E. Lochridge, because they had been prepared at st and under his constant advice and supervision. He disese tables and agreed with Mr. Lochridge concerning their ice. (7966–7969.)

n discussed the effect o typhoid rate of the large number o expositions in c cited his investigations with t of the olumbian Exposition and the of adelphia, and expressed the ase in typhoid in St. tributed to the influx urchase Exposition.

The witness then stated that circulars sent by boards of health to physicians urging them to report cases of typhoid fever could have no influence on the reporting of deaths from the disease for the reason that physicians are legally bound to report deaths in any event before a burial permit can be obtained. (7970–7971.)

The testimony of Professor Zeit in which he attributed extensive destructive effects on typhoid-fever germs to the toxic products of saprophytes in sewage was presented to the witness. He stated that while many authorities agree with Doctor Zeit, others do not accept that view, and he quoted an experiment made by himself and D. D. Jackson in 1893 in which the very point under consideration was studied. A portion of sewage was very carefully freed from all microbes present, saprophytic or parasitic, by filtration. In this condition the sewage was free from all the living organisms, but contained their toxic products. A portion of this filtrate was then seeded with typhoid-fever microbes to the number of 329 per cubic centimeter. If the toxic products of the saprophytes had been capable of destroying typhoid germs, these would have gradually declined in number. The facts were, however, that one hour after inoculation there were 333 per cubic centimeter, twenty-four hours later there were 63,198 per cubic centimeter, and two days later they were innumerable. This specimen was kept at blood heat. The germs were carefully examined to make certain that they were true typhoid bacilli, and the culture was then placed in the ice chest. Six days later the number of typhoid germs had fallen to 888,000 per cubic centimeter; twelve days after the seeding the number present was 832,100; twenty days after, 375,000, and thirty-six days after, 56,500. These experiments had satisfied the witness that whether or not typhoid germs ultimately disappear in sewage they are not readily destroyed by the toxic products of saprophytes, but rather multiply and live long in their presence. The witness also cited a similar experiment of Doctor Horrocks in which abundant typhoid-fever germs were found in sewage filtered in the same way after forty-two days. (7971–7972.)

The witness stated that he had examined all the chemical and bacteriological data introduced into evidence by the defendants, and while he had thereby obtained a much better knowledge of the processes of chemical and bacterial purification going on at certain times and seasons in Illinois River, he had failed to discover any reason for changing his original opinion that the principal part of the increase of typhoid fever in St. Louis since January, 1900, has been due to the presence of deleterious elements contained in the public water supply derived from the unpurified sewage of the city of Chicago. (7973.)

DECISION OF THE SUPREME COURT.

The report of the testimony of which the above is a digest was presented to the Supreme Court of the United States, with voluminous briefs and arguments by the parties to the suit, in the October term of 1905. The following is the full text of the opinion of the court, as rendered by Mr. Justice Holmes February 19, 1906:

This is a suit brought by the State of Missouri to restrain the discharge of the sewage of Chicago through an artificial channel into the Desplaines River, in the State of Illinois. That river empties into the Illinois River, and the latter empties into the Mississippi at a point about forty-three miles above the city of St. Louis. It was alleged in the bill that the result of the threatened discharge would be to send fifteen hundred tons of poisonous filth daily into the Mississippi, to deposit great quantities of the same upon the part of the bed of the last-named river belonging to the plaintiff. and so to poison the water of that river, upon which various of the plaintiff's cities, towns and inhabitants depended, as to make it unfit for drinking, agricultural, or manufacturing purposes. It was alleged that the defendant sanitary district was acting in pursuance of a statute of the State of Illinois and as an agency of that State The case is stated at length in 180 U. S. 208, where a demurrer to the bill was overruled. A supplemental bill alleges that since the filing of the original bill the drainage canal has been opened and put into operation and has produced and is producing all the evils which were apprehended when the injunction first was asked. The answers deny the plaintiff's case, allege that the new plan sends the water of the Illinois River into the Mississippi much purer than it was before, that many towns and cities of the plaintiff along the Missouri and Mississippi discharge their sewage into those rivers, and that if there is any trouble the plaintiff must look nearer home for the cause.

The decision upon the demurrer discussed mainly the jurisdiction of the Court, and, as leave to answer was given when the demurrer was overruled, naturally there was no very precise consideration of the principles of law to be applied if the plaintiff should prove its case. That was left to the future with the general intimation that the nuisance must be made out upon determinate and satisfactory evidence, that it must not be doubtful and that the danger must be shown to be real and immediate. The nuisance set forth in the bill was one which would be of international importance—a visible change of a great river from a pure stream into a polluted and poisoned ditch. The only question presented was whether as between the States of the Union this Court was competent to deal with a situation which, if it arose between independent sovereignties, might lead to war. Whatever differences of opinion there might be upon matters of detail, the jurisdiction and authority of this Court to deal with such a case as that is not open to doubt. But the evidence now is in, the actual facts have required for their establishment the most ingenious experiments, and for their interpretation the most subtle speculations, of modern science, and therefore it becomes necessary at the present stage to consider somewhat more nicely than heretofore how the evidence it is to be approached.

The first question to be answered was put in the well-known case of the Wheeling bridge. *Pennsylvania* v. *Wheeling & Belmont Bridge Co.*, 13 How. 518. In that case, also, there was a bill brought by a State to restrain a public nuisance, the erection of a bridge alleged to obstruct navigation, and a supplemental bill to abate it after it was erected. The question was put most explicitly by the dissenting judges but it was accepted by all as fundamental. The Chief Justice observed that if the bridge was a nuisance it was an offence against the sovereignty whose laws had been violated, and he asked what sovereignty that was. 13 How. 561. Daniel, J., 13 How. 599. (See also *Kansas* v. *Colorado*, 185 U. S. 125.) It could not be Virginia, because that State had purported to authorize it by statute. The Chief Jus-

tice found no prohibition by the United States. 13 How. 580. No third source of law was suggested by any one. The majority accepted the Chief Justice's postulate, and found an answer in what Congress had done.

It hardly was disputed that Congress could deal with the matter under its power to regulate commerce. The majority observed that although Congress had not declared in terms that a State should not obstruct the navigation of the Ohio, by bridges, yet it had regulated navigation upon that river in various ways and had sanctioned the compact between Virginia and Kentucky when Kentucky was let into the Union. By that compact the use and navigation of the Ohio, so far as the territory of either State lay thereon, was to be free and common to the citizens of the United States. The compact, by the sanction of Congress, had become a law of the Union. A State law which violated it was unconstitutional. Obstructing the navigation of the river was said to violate it, and it was added that more was not necessary to give a civil remedy for an injury done by the obstruction. 13 How. 565, 566. At a later stage of the case, after Congress had authorized the bridge, it was stated again in so many words that the ground of the former decision was that "the act of the legislature of Virginia afforded no authority or justification. It was in conflict with the acts of Congress, which were the paramount law." 18 How. 421, 429.

In the case at bar, whether Congress could act or not, there is no suggestion that it has forbidden the action of Illinois. The only ground on which that State's conduct can be called in question is one which must be implied from the words of the Constitution. The Constitution extends the judicial power of the United States to controversies between two or more States and between a State and citizens of another State, and gives this Court original jurisdiction in cases in which a State shall be a party. Therefore, if one State raises a controversy with another, this Court must determine whether there is any principle of law and, if any, what, on which the plaintiff can recover. But the fact that this Court must decide does not mean, of course, that it takes the place of a legislature. Some principles it must have power to declare. For instance, when a dispute arises about boundaries, this Court must determine the line, and in doing so must be governed by rules explicitly or implicitly recognized. *Rhode Island* v. *Massachusetts*, 12 Pet. 657, 737. It must follow and apply those rules, even if legislation of one or both of the States seems to stand in the way. But the words of the Constitution would be a narrow ground upon which to construct and apply to the relations between States the same system of municipal law in all its details which would be applied between individuals. If we suppose a case which did not fall within the power of Congress to regulate, the result of a declaration of rights by this Court would be the establishment of a rule which would be irrevocable by any power except that of this Court to reverse its own decision, an amendment of the Constitution, or possibly an agreement between the States sanctioned by the legislature of the United States.

The difficulties in the way of establishing such a system of law might not be insuperable, but they would be great and new. Take the question of prescription in a case like the present. The reasons on which prescription for a public nuisance is denied or may be granted to an individual as against the sovereign power to which he is subject have no application to an independent State. See 1 Oppenheim, International Law, 293, §§ 242, 243. It would be contradicting a fundamental principle of human nature to allow no effect to the lapse of time, however long, *Davis* v. *Mills*, 194 U. S. 451, 457, yet the fixing of a definite time usually belongs to the legislature rather than the courts. The courts did fix a time in the rule against perpetuities, but the usual course, as in the instances of statutes of limitation, the duration of patents, the age of majority, etc., is to depend upon the lawmaking power.

It is decided that a case such as is made by the bill may be a ground for relief. The purpose of the foregoing observations is not to lay a foundation for departing from that decision, but simply to illustrate the great and serious caution with which

it is necessary to approach the question whether a case is proved. It may be imagined that a nuisance might be created by a State upon a navigable river like the Danube, which would amount to a *casus belli* for a State lower down, unless removed. If such a nuisance were created by a State upon the Mississippi the controversy would be resolved by the more peaceful means of a suit in this Court. But it does not follow that every matter which would warrant a resort to equity by one citizen against another in the same jurisdiction equally would warrant an interference by this Court with the action of a State. It hardly can be that we should be warranted in declaring statutes ordaining such action void in every instance where the circuit court might intervene in a private suit, upon no other ground than analogy to some selected system of municipal law, and the fact that we have jurisdiction over controversies between States.

The nearest analogy would be found in those cases in which an easement has been declared in favor of land in one State over land in another. But there the right is recognized on the assumption of a concurrence between the two States, the one, so to speak, offering the right, the other permitting it to be accepted. *Mannville Co.* v. *Worcester*, 138 Mass. 89. But when the State itself is concerned and by its legislation expressly repudiates the right set up, an entirely different question is presented.

Before this Court ought to intervene the case should be of serious magnitude, clearly and fully proved, and the principle to be applied should be one which the Court is prepared deliberately to maintain against all considerations on the other side. See *Kansas* v. *Colorado*, 185 U. S. 125.

As to the principle to be laid down the caution necessary is manifest. It is a question of the first magnitude whether the destiny of the great rivers is to be the sewers of the cities along their banks or to be protected against everything which threatens their purity. To decide the whole matter at one blow by an irrevocable fiat would be at least premature. If we are to judge by what the plaintiff itself permits, the discharge of sewage into the Mississippi by cities and towns is to be expected. We believe that the practice of discharging into the river is general along its banks, except where the levees of Louisiana have led to a different course. The argument for the plaintiff asserts it to be proper within certain limits. These are facts to be considered. Even in cases between individuals some consideration is given to the practical course of events. In the black country of England parties would not be expected to stand upon extreme rights. *St. Helen's Smelting Co.* v. *Tipping*, 11 H. L. C. 642. See *Boston Ferrule Co.* v. *Hills*, 159 Mass. 147, 150. Where, as here, the plaintiff has sovereign powers and deliberately permits discharges similar to those of which it complains, it not only offers a standard to which the defendant has the right to appeal, but, as some of those discharges are above the intake of St. Louis, it warrants the defendant in demanding the strictest proof that the plaintiff's own conduct does not produce the result, or at least so conduce to it that courts should not be curious to apportion the blame.

We have studied the plaintiff's statement of the facts in detail and have perused the evidence, but it is unnecessary for the purposes of decision to do more than give the general result in a very simple way. At the outset we can not but be struck by the consideration that if this suit had been brought fifty years ago it almost necessarily would have failed. There is no pretense that there is a nuisance of the simple kind that was known to the older common law. There is nothing which can be detected by the unassisted senses—no visible increase of filth, no new smell. On the contrary, it is proved that the great volume of pure water from Lake Michigan which is mixed with the sewage at the start has improved the Illinois River in these respects to a noticeable extent. Formerly it was sluggish and ill smelling. Now it is a comparatively clear stream to which edible fish have returned. Its water is drunk by the fishermen, it is said without evil results. The plaintiff's case depends upon an inference of the unseen.

It draws the inference from two propositions. First, that typhoid fever has increased considerably since the change and that other explanations have been disproved, and second, that the bacillus of typhoid can and does survive the journey and reach the intake of St. Louis in the Mississippi.

We assume the now prevailing scientific explanation of typhoid fever to be correct. But when we go beyond that assumption everything is involved in doubt. The data upon which an increase in the deaths from typhoid fever in St. Louis is alleged are disputed. The elimination of other causes is denied. The experts differ as to the time and distance within which a stream would purify itself. No case of an epidemic caused by infection at so remote a source is brought forward and the cases which are produced are controverted. The plaintiff obviously must be cautious upon this point, for if this suit should succeed many others would follow, and it not improbably would find itself a defendant to a bill by one or more of the States lower down upon the Mississippi. The distance which the sewage has to travel (357 miles) is not open to debate, but the time of transit to be inferred from experiments with floats is estimated at varying from eight to eighteen and a half days, with forty-eight hours more from intake to distribution, and when corrected by observations of bacteria is greatly prolonged by the defendants. The experiments of the defendants' experts lead them to the opinion that a typhoid bacillus could not survive the journey, while those on the other side maintain that it might live and keep its power for twenty-five days or more, and arrive at St. Louis. Upon the question at issue, whether the new discharge from Chicago hurts St. Louis, there is a categorical contradiction between the experts on the two sides.

The Chicago drainage canal was opened on January 17, 1900. The deaths from typhoid fever in St. Louis, before and after that date, are stated somewhat differently in different places. We give them mainly from the plaintiff's brief: 1890, 140; 1891, 165; 1892, 441; 1893, 215; 1894, 171; 1895, 106; 1896, 106; 1897, 125; 1898, 95; 1899, 131; 1900, 154; 1901, 181; 1902, 216; 1903, 281. It is argued for the defendants that the numbers for the later years have been enlarged by carrying over cases which in earlier years would have been put into a miscellaneous column (intermittent, remittent, typho-malaria, etc., etc.), but we assume that the increase is real. Nevertheless, comparing the last four years with the earlier ones, it is obvious that the ground for a specific inference is very narrow, if we stopped at this point. The plaintiff argues that the increase must be due to Chicago, since there is nothing corresponding to it in the watersheds of the Missouri or Mississippi. On the other hand, the defendants point out that there has been no such enhanced rate of typhoid on the banks of the Illinois as would have been found if the opening of the drainage canal were the true cause.

Both sides agree that the detection of the typhoid bacillus in the water is not to be expected. But the plaintiff relies upon proof that such bacilli are discharged into the Chicago sewage in considerable quantities; that the number of bacilli in the water of the Illinois is much increased, including the *Bacillus coli communis*, which is admitted to be an index of contamination, and that the chemical analyses lead to the same inference. To prove that the typhoid bacillus could make the journey an experiment was tried with the *Bacillus prodigiosus*, which seems to have been unknown, or nearly unknown, in these waters. After preliminary trials, in which these bacilli emptied into the Mississippi near the mouth of the Illinois were found near the St. Louis intake and in St. Louis in times varying from three days to a month, 107 barrels of the same, said to contain 1,000,000,000 bacilli to the cubic centimeter, were put into the drainage canal near the starting point on November 6, and on December 4 an example was found at the St. Louis intake tower. Four others were found on the three following days, two at the tower and two at the mouth of the Illinois. As this bacillus is asserted to have about the same length of life in sunlight in living waters as the *Bacillus typhosus*, although it is a little more hardy, the experiment is thought to [illegible] element of the plaintiff's case, although the very small number found

in many samples of water is thought by the other side to indicate that practically no typhoid germs would get through. It seems to be conceded that the purification of the Illinois by the large dilution from Lake Michigan (nine parts or more in ten) would increase the danger, as it now generally is believed that the bacteria of decay, the saprophytes, which flourish in stagnant pools, destroy the pathogenic germs. Of course the addition of so much water to the Illinois also increases its speed.

On the other hand, the defendants' evidence shows a reduction in the chemical and bacterial accompaniments of pollution in a given quantity of water, which would be natural in view of the mixture of nine parts to one from Lake Michigan. It affirms that the Illinois is better or no worse at its mouth than it was before, and makes it at least uncertain how much of the present pollution is due to Chicago and how much to sources further down, not complained of in the bill. It contends that if any bacilli should get through they would be scattered and enfeebled and would do no harm. The defendants also set against the experiment with the *Bacillus prodigiosus* a no less striking experiment with typhoid germs suspended in the Illinois River in permeable sacks. According to this the duration of the life of these germs has been much exaggerated, and in that water would not be more than three or four days. It is suggested, by way of criticism, that the germs may not have been of normal strength, that the conditions were less favorable than if they had floated down in a comparatively unchanging body of water, and that the germs may have escaped, but the experiment raises at least a serious doubt. Further, it hardly is denied that there is no parallelism in detail between the increase and decrease of typhoid fever in Chicago and St. Louis. The defendants' experts maintain that the water of the Missouri is worse than that of the Illinois, while it contributes a much larger proportion to the intake. The evidence is very strong that it is necessary for St. Louis to take preventive measures, by filtration or otherwise, against the dangers of the plaintiff's own creation or from other sources than Illinois. What will protect against one will protect against another. The presence of causes of infection from the plaintiff's action makes the case weaker in principle as well as harder to prove than one in which all came from a single source.

Some stress was laid on the proposition that Chicago is not on the natural watershed of the Mississippi, because of a rise of a few feet between the Desplaines and the Chicago rivers. We perceive no reason for a distinction on this ground. The natural features relied upon are of the smallest. And if under any circumstances they could affect the case, it is enough to say that Illinois brought Chicago into the Mississippi watershed in pursuance not only of its own statutes, but also of the acts of Congress of March 30, 1822, c. 14, 3 St. 659, and March 2, 1827, c. 51, 4 St. 234, the validity of which is not disputed. *Wisconsin* v. *Duluth*, 96 U. S. 379. Of course these acts do not grant the right to discharge sewage, but the case stands no differently in point of law from a suit because of the discharge from Peoria into the Illinois, or from any other or all the other cities on the banks of that stream.

We might go more into detail, but we believe that we have said enough to explain our point of view and our opinion of the evidence as it stands. What the future may develop of course we can not tell. But our conclusion upon the present evidence is that the case proved falls so far below the allegations of the bill that it is not brought within the principles heretofore established in the cause.

Bill dismissed without prejudice.

True copy.

Test:

Clerk Supreme Court, U. S.

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{ O, Underground Waters, 69

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

UNDERGROUND WATERS OF MISSOURI

IEIR GEOLOGY AND UTILIZATION

BY

EDWARD M. SHEPARD

WASHINGTON
GOVERNMENT PRINTING OFFICE
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UNDERGROUND WATERS OF MISSOURI: THEIR GEOLOGY AND UTILIZATION.

By Edward M. Shepard.

INTRODUCTION.

With the advance in sanitary science the value and importance of a e water supply for towns and cities, as well as for country dis- ts, are being each year more strongly emphasized. The rapid set- g of the country has made surface waters very liable to contamina- , and the demand for water from deeper sources, less exposed to anic impurities, is becoming more and more marked.

The rapid growth of Missouri—the 1900 census placing her fifth in ulation among the States of the Union—has brought this demand particular notice in this State. Many villages have grown to ns and are looking for a suitable supply of water, not only for nestic uses, but also as a means of protection from fire. Many es have wholly outgrown the capacity of their source of water sup- and need additional or new and larger sources. The largest cities e constantly to face the increasing contamination of the rivers n which their water is derived, and the necessity of seeking some source has stimulated inquiries for information in regard to esian conditions in the State. In the hope of answering such uiries to some extent this report has been prepared.

Those who have studied the subject of artesian wells understand the iculties which confront the geologist in attempting to explain or cribe the conditions which govern their distribution. These diffi- ties are especially apparent in Missouri, as so little has been done ard elucidating the problems incident to the folding and faulting he geologic horizons of this great State. The sinking of deep wells been largely confined to the mining districts, and they have been aparatively few i[illegible]r, while it is but recently that the devel- nent of the oil [illegible]ansas has stimulated prospecting in the thern and wes[illegible] Missouri.

It is unfortunate that the geologist can not be present to collect for himself the drillings from deep wells and note the thicknesses of the strata passed through, since, as a rule, the records are rather negligently kept. Samples of cuttings are carelessly preserved, the labels are either lost or destroyed, and even the records themselves often disappear. Little or no attention is paid to the different flows or to the quality of the water. In some cases these wells are grouped in or near certain mining localities and in others a considerable distance, covering several counties, intervenes between them, for which reasons deductions made by the geologist from cross sections based on well-record data may not be strictly accurate. Fortunately, however, there are a few wells in Missouri which were drilled under the careful supervision of geologists, and the writer has been able to study a number of cases where samples of drillings and an accurate log have been carefully preserved by intelligent drillers. On the other hand, the valuable information that might have been given by many deep wells, drilled at great expense, has been wholly lost. Records that would have been of inestimable value to the geologist and the public have disappeared, and in some cases the well has been abandoned. It is to be hoped that in the future not only drillers, but owners of such wells will see to it that records and samples of drillings are preserved and that information regarding them is given either to the State or to the United States Geological Survey.

The writer wishes here to express his appreciation to Mr. M. L. Fuller, under whose direction this work has been done; to Mr. W. B. Johnson, of Memphis, Tenn., who rendered invaluable assistance in making many well records accessible; to Mr. C. B. Bailey, of Wynne, Ark.; Mr. Thomas Beckwith, of Charleston, Mo.; Messrs. W. G. Lanhan and W. C. Davis, engineers for the Memphis Water Company; Mr. W. E. Pratt, of Samburg, Tenn.; Mr. W. B. Beckman, of Blytheville, Ark.; to Dr. E. R. Buckley, State geologist of Missouri; to Mr. R. Hawkins, of Chillicothe; and many others who have cheerfully given the result of their observations.

HISTORICAL FACTS.

The term "artesian" is derived from the province of Artois, France, where one of the first wells of this character was sunk, and it dates back probably to the twelfth century. Norton, in his Artesian Wells of Iowa,[a] calls attention to the fact that at Modena, in northern Italy, are wells of about the same antiquity as those of Artois. They have been in use for many centuries in Austria. It is believed that they have a great antiquity in China; and Tchihatchef affirmed, in an address before the British Association in 1882, that the ancient Greeks sunk artesian wells in Sahara, at Baalbek, and at other points. One

[a] Norton, W. H., Ann. Rept. Iowa Geol. Survey, vol. 6, 1897, p. 123.

of the earliest wells sunk in this country, so far as it has been possible to determine, was bored for salt at Spalding, near Rensselaer, Ralls County, Mo., about 1823.

It is most unfortunate that the term artesian is used so loosely. Originally it designated flowing wells only, but in later years it has been also applied to deep wells that do not flow. Norton has suggested the term "subartesian" for nonflowing deep wells, and it is very desirable that some such distinction should be made. In this report each well will be designated as "flowing" or "nonflowing."

REQUISITE CONDITIONS FOR FLOWING ARTESIAN WELLS.

In a general way the principal requisite for the production of a flowing-water well is the direct opposite of that for a gas well. Both require, first, a reservoir—that is, a stratum of coarse-grained or granular rock, which may be either a sandstone or a coarse-grained limestone; second, an impervious protecting cap rock, which is generally a shale or a very compact limestone; but the third and most important point, in which the two classes of wells differ, is that the gas collects at the crest of a fold of strata, *i. e.*, at the summit of an anticline, while the water accumulates in a basin or synclinal trough. These two classes of wells differ also in the source from which they are derived. The gas usually originates in the carbonaceous shale that underlies the reservoir, while the source of the water is frequently many miles away, at the point where the rock which forms its reservoir outcrops, necessarily always at a higher level than that from which the well starts. A sufficient rainfall in its catchment basin is also an essential condition for the existence of a successful artesian well. Williams[a] has shown that—

> A rainfall of 30 inches per year, which is well within the average rainfall of the eastern United States [as well as of the State of Missouri], would supply to the gathering area of a 100-foot stratum, dipping at an angle of 1°, 3,400 barrels of water a year for every foot in width across the outcrop, of which, if but one-third is taken up by the stratum, upward of 1,100 barrels per year will be stored in every foot of its width. Hence the enormous flow from some noted artesians need excite no surprise. An artesian well in the city of Louisville is said to yield 330,000 gallons every twenty-four hours, from a depth of 2,086 feet. One in the city of Paris, the Grenelle well, discharges over half a million gallons per day from a depth of 1,806 feet, while one bored by a French engineer in the Sahara Desert is said to have yielded at the outset 1,000 gallons per minute, or about 1,500,000 gallons per day.

Gas fields are, as a rule, confined to certain geologic horizons. For example, in Kansas and Missouri gas is found only at the base of the Pennsylvanian, in the Cherokee shale. It is also true that certain geologic horizons are eminently water bearers. Later in this report, for example, it is shown that the St. Peter sandstone, where the other conditions are favorable, is one of the most prominent reservoirs for

[a] Williams, S. J., Applied Geology, New York, 1886, p. 62.

artesian waters. Further, different water-bearing horizons vary decidedly in the quality of waters produced. In the loose incoherent sands of the Tertiary is found an abundance of good water, though it is inclined to be somewhat chalybeate. In the sandstones of the Pennsylvanian sulphur and saline waters may be expected. In the Hannibal formation of the Kinderhook group magnesium-sulphate (Epsom salts) waters are the general rule. At the base of the porous upper part of the Burlington hard but pure waters are found. The water of the St. Peter sandstone, if it has not traveled too far and become laden with impurities, is likely to be soft and fresh.

As has been stated, artesian waters are sometimes found in basins—that is, in old lake or estuary beds. Under such conditions the water falling on surrounding outcropping strata drains into the basin from all sides. The accompanying diagram (fig. 1), modified from Williams, gives an idea of a basin which has been faulted on one side. The catchment area is higher on each side than in the middle, and the upturned edges of the strata outcrop there. The porous sandstone

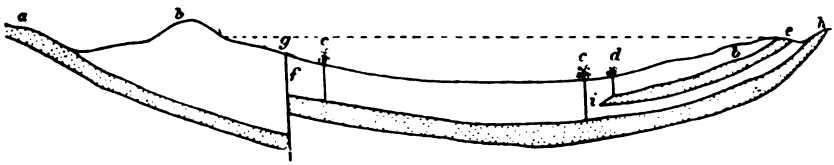


FIG. 1.—Diagram illustrating essential conditions for artesian wells and springs.

beds *a*, *e*, and *h* are covered above and below by impervious shale beds. Wells drilled through the upper shale at any point in the basin, below the outcropping edges, will tap the water under pressure and will flow. Sometimes strata gradually change in character, as illustrated in *e* in the diagram, the sandstone bed merging into shale. This sandstone bed, when tapped, as at *d*, will yield flowing water. It is clear that the rainfall soaking into the outcropping edges of the porous strata passes downward in these beds and, being under pressure, will rise, when tapped, as at *c* and *d*, and flow to the surface with a force proportionate to the height of the head above the mouth of the well. If a well were sunk at *b*, water would not flow, because *b* is at the same height as the head *a*. At *g* the strata have been faulted, and those to the left have gone down. Such a fault line as this frequently marks the passage of water that rises in springs, as at *g*. Water from a well drilled at *c* would rise with much greater force than from a well at *d*, because the head at *c* is higher.

If a basin was formerly an estuary of the sea, which has been tilted so that the mouth has been elevated, or if the mouth has been filled

up with impervious deposits so that the salt water has slowly evaporated, leaving the basin to be subsequently filled with alternating deposits of sand and clay, all the conditions requisite for brine wells will be found. Such conditions explain the brine wells and springs of Saline and Howard counties, and are more fully described in the text (pp. 80–81).

Another common condition favoring the collection of artesian waters is found in basins which contain sand, with an impervious clay layer above, and into which the drainage comes from three directions. As an example of this the conditions in southeastern Missouri may be cited. The valley of the Mississippi lies in a trough, between the Ozarks on the west and the Kentucky and Tennessee plateau on the east. Here powerful drainage flows in from the north, the west, and the east. This is one of the strongest artesian basins in the interior States.

Again, the source of artesian waters may be from one direction only—as, for example, on the long, gentle slope of a fold, where the head is higher than the point at which the well is drilled. Such is commonly the case in many parts of the State.

Faulting may produce artesian conditions where they would not otherwise be present, the displacement bringing an impervious stratum against the porous, water-bearing stratum.

Another consideration of much importance as regards the abundance of water supply is the area of the outcrop of the porous beds, or the breadth of the absorbing surface exposed. Williams [a] has shown the great extent of the catchment area where only a slight dip is found. He says: "The breadth of exposure on a level surface of beds 100 feet thick with a dip of 1° would be a trifle more than a mile, and for 2° dip about one-half mile, the breadth of surface exposed varying inversely as the dip. Hence a moderate degree of dip will give a greater extent of gathering ground, or area of catchment, as it is often termed."

VARIATION IN THE FLOW OF ARTESIAN WELLS.

Artesian wells sometimes vary in their flow. Some gradually weaken until their flow ceases altogether; others stop flowing when wells near by are pumped, as illustrated by those of the De Soto group; and still others have periodic variations or fluctuations in their discharge. Such fluctuations are due in many cases, no doubt, to barometric variation in pressure; near the seashore they may be due to tidal influence; in some cases they are believed to be due to a siphon action, when the conditions in the waterway are favorable.

[a] Williams, S. J., Applied Geology, New York, 1886, p. 61.

The uses of artesian wells, aside from their value in supplying w for domestic purposes, are, among others, as a source of mi waters; to furnish water for irrigation; for protection against for the development of power for manufacturing purposes; fo production of heat. Last, but not least, the importance of the sian well as a geologic agent is a matter which challenges atte and which has heretofore been entirely overlooked.[a]

The waters of certain wells possess mineral constituents whic der them valuable therapeutic agents, both for internal and ex use, and these give rise to the establishment of health resorts. of the finest of such resorts in the West are located in this Stat derive their water from deep wells.

The abundance of rainfall in Missouri, as shown by the table close of this section, and its excellent drainage system render i tion unnecessary; but the value of artesian wells for such a pu in the far West is largely recognized. One of the most imp services rendered by the water resources branch of the United Geological Survey is the location of storage reservoirs and th lining of artesian districts for the irrigation of the arid regi the West. The basins located between many of the ranges Rocky Mountain system are deserts. Fortunately the strata s from the frequently snow-capped mountains present favorabl ditions for artesian waters, and large areas are now being irri by means of flowing wells.

In several cases, where the water from an artesian well has p too saline for domestic purposes it has been found that this char istic has rendered it of particular value in extinguishing fires.

Darton,[b] in his report on "Artesian wells of a portion of the tas," describes the utilization of power from some artesian w producing electrical energy and running mills. The pressure number of cases reaches 100 to 150 pounds. There are a num wells in Missouri that have a considerable pressure, but are not u for power.

None of the wells of this State have water of a high tempe though some of them reach a considerable depth.

[a] See Shepard, E. M., New Madrid earthquake: Jour. Geol., Vol. 13, 1905, p. [illegible]

[b] Darton, N. H., Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. [illegible]

Average annual precipitation in Missouri for ten years, by counties.

	Inches.		Inches.		Inches.
.....	38	Greene.....	43	Ozark.....	44
.....	35	Grundy.....	36	Pemiscot.....	45
.....	34	Harrison.....	36	Perry.....	42
.....	39	Henry.....	40	Pettis.....	37
.....	47	Hickory.....	43	Phelps.....	42
.....	46	Holt.....	37	Pike.....	38
.....	40	Howard.....	37	Platte.....	35
.....	40	Howell.....	43	Polk.....	43
.....	45	Iron.....	45	Pulaski.....	42
.....	36	Jackson.....	36	Putnam.....	36
.....	34	Jasper.....	46	Ralls.....	37
.....	45	Jefferson.....	41	Randolph.....	37
.....	37	Johnson.....	37	Ray.....	37
.....	39	Knox.....	36	Reynolds.....	43
.....	42	Laclede.....	44	Ripley.....	45
deau.....	44	Lafayette.....	37	Saline.....	35
.....	37	Lawrence.....	47	Schuyler.....	35
.....	44	Lewis.....	36	Scotland.....	35
.....	38	Lincoln.....	38	Scott.....	44
.....	43	Linn.....	37	Shannon.....	43
.....	36	Livingston.....	36	Shelby.....	38
.....	45	McDonald.....	47	St. Charles.....	41
.....	34	Macon.....	37	St. Clair.....	42
.....	35	Madison.....	45	St. Francois.....	43
.....	35	Maries.....	41	Ste. Genevieve.....	42
.....	38	Marion.....	38	St. Louis.....	39
.....	37	Mercer.....	37	Stoddard.....	46
.....	42	Miller.....	41	Stone.....	47
.....	45	Mississippi.....	43	Sullivan.....	37
.....	43	Moniteau.....	38	Taney.....	46
.....	37	Monroe.....	38	Texas.....	41
.....	36	Montgomery.....	39	Vernon.....	42
.....	42	Morgan.....	39	Warren.....	40
.....	44	New Madrid.....	46	Washington.....	42
.....	46	Newton.....	46	Wayne.....	44
.....	40	Nodaway.....	36	Webster.....	43
.....	39	Oregon.....	43	Worth.....	35
.....	36	Osage.....	40	Wright.....	43

TOPOGRAPHY.

raphically Missouri is naturally divided into six great dis-
he northwest plateau, the north-central prairie region, the
t. Francis dome, the Ozark border, the southeastern lowlands,
Lincoln Ridge, all of which are outlined on the accompanying
. 2).

NORTHWEST PLATEAU DISTRICT.

orthwest plateau includes the elevated portion of the north-
third of the State and is bounded, approximately, by the 900-

foot contour indicated on the map. This plateau gently rises in altitude to the northwest corner of the State, where its elevation is over 1,200 feet. Geologically, however, the strata generally dip about 10 or 15 feet to the mile in a northwesterly direction, thus burying to a considerable depth the Pennsylvanian rocks, which outcrop on the southern border of the district. The surface is relatively smooth and gently rolling, slightly trenched by the rivers which drain it and covered with a mantle of drift, which is composed on the surface of a fine sandy silt and clay. Along Missouri River, however, are large deposits of loess. The valleys of the smaller streams are usually broad, with gentle slopes, owing to the character of the underlying rocks, which are largely shales and sandstones. Rarely, where the streams cut into thin limestone beds, a greater irregularity of the surface is noticed.

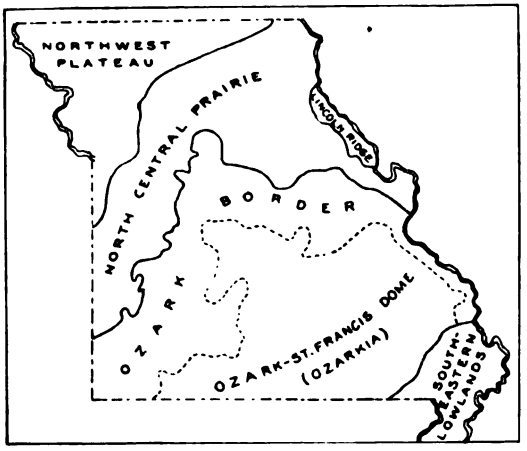


FIG. 2.—Map showing topographic districts of Missouri.

NORTH-CENTRAL PRAIRIE DISTRICT.

The north-central prairie is bounded on the south by an arbitrary line that starts on Mississippi River, in St. Charles County, and runs in a northwesterly direction until it strikes the southern 900-foot contour north of Cooper County. Thence this line runs in a southerly and southwesterly direction, leaving the State in Barton County. This irregular prairie district is deeply bisected by Missouri River and is trenched on the north and south by the tributaries of the Missouri. The altitude of the flood plain of the river at the lowest point in this district is a little over 600 feet. It rises gradually to the northeast as far as the Iowa line, where its altitude is about 1,200 feet. From the Missouri southwest to the Kansas line it reaches an altitude of from 800 to 900 feet.

OZARK-ST. FRANCIS DOME DISTRICT.

The Ozark-St. Francis dome district includes an elevated elliptical plateau, having a northeast-southwest trend. It extends in a broad belt from a point near Mississippi River to the Arkansas line. The northwestern limit of this district is marked on the topographic map (fig. 2) by an irregular line. The general axis extends from Iron

County southwestward, and leaves the State near the southeast corner of Barry County. As a rule, the strata dip gently at right angles to this axis. The highest point in this district, as well as in the State, is Taum Sauk, the crest of the St. Francis Mountains, in Iron County, which reaches an elevation of 1,800 feet. The crest of the Ozarks is reached at Cedar Gap, in Wright County, at an elevation of 1,700 feet. The geologic formations involved in the Ozark dome are mainly hard silico-magnesian limestone and more or less indurated sandstones. The drainage to the north and west of the main axis is into Osage and Missouri rivers. To the south it is mainly through James Fork, Bryants Creek, Current River, and Black River into White River, and through St. Francis River into the Mississippi. The Current, flowing southeastward, and Piney Fork of the Gasconade, flowing northward, nearly bisect the dome. The streams flowing across the dome on either side have cut less deeply than those along the border of the Ozarks. This is due to the nature of the rocks and the slope of the streams.

OZARK BORDER DISTRICT.

The Ozark border district is a region marked by a deeper trenching of the streams and by numerous sink holes, which are a striking characteristic of the region. Near the inner margin of this area are found many of the great springs of the Ozarks, which, in a number of cases, are the outlets of underground rivers and are of phenomenal size. The scenery along this margin is unique. It is here that the valleys are deepest and the bluffs most abrupt and picturesque. The outer margin of the district gradually merges to the north into the prairie district.

SOUTHEASTERN LOWLANDS DISTRICT.

The southeastern lowlands district includes that part of the State which lies southeast of a line running from a point near Cape Girardeau southwestward to a point in the southeast corner of Ripley County and approximately marked by the 400-foot contour. The line of demarcation between the Ozark dome and the lowlands is somewhat abrupt, as there is no border district on the southeast of the dome. This is, in some respects, the most striking topographic district in the State. It has a width of about 50 miles. In a general way the surface is nearly a level plain, broken by the irregular Crowleys Ridge, which extends northeastward from Arkansas to Commerce, Mo., on the Mississippi. This ridge is broader at the south and gradually narrows to the northeast, being finally broken into several isolated elevations, such as Ringer Hill, Cow Hill, Lost Hill, Birds Hill, and Benton Ridge, that stand up boldly in the midst of the general plain. It is a remnant of a former coastal

plain and is being rapidly reduced by erosion. The slope is more gentle toward the east, with a rather abrupt escarpment in places on the west, facing the St. Francis Valley. Marbut[a] has shown how Crowleys Ridge was left by the change in the channel of Mississippi River, which formerly flowed between the Ozark highlands and this ridge and emptied into what was then Ohio River, near Helena, Ark. Later, after several changes in its course, the Mississippi was captured by the Ohio, and its present flood plain is the low region east of Crowleys Ridge. It should be remembered that the drainage of the Ozarks empties into this lowland and helps, with the drainage from Illinois on the north and from Kentucky and Tennessee on the east, to form a very remarkable artesian basin. The majority of the streams on the southern slopes of the Ozarks bend abruptly at right angles on entering the St. Francis basin. The flood plain of the Mississippi east of Crowleys Ridge is from 100 to 150 feet lower than the present top of the ridge, and shows the amount of erosion that has taken place from the original level of the coastal plain, which was undoubtedly considerably higher than the present altitude of the ridge. The sections given across this district (p. 35) show the striking manner in which Crowleys Ridge rises from the dead level of the lowlands, like an island in the sea. With the exception of a low dome about New Madrid, elevated from 20 to 30 feet, the general level is unbroken, save by low ridges alternating with narrow, tortuous lakes, rivers, and swamps running in more or less irregular parallel lines between Crowleys Ridge and Mississippi River. Toward the south of the lowland district there is a general gentle slope away from the Mississippi to the southwest.

LINCOLN RIDGE DISTRICT.

Lincoln Ridge is an anticlinal axis entering Missouri in Lincoln County from Calhoun County in Illinois. This anticline has been called the Cap au Grès fault. Its main axis has a general northerly course, diverging slightly to the west. It may be traced in an irregular line through Lincoln, Pike, Ralls, and a part of Marion counties. The uplift has given rise to a characteristic topography throughout this region. The eastern side, toward the Mississippi, is more or less abrupt, being seamed and scored by deep, narrow valleys alternating with rounded and in many cases conical hills. The different geologic formations, from their varying texture, illustrate the changing degrees of erosion, the shales giving gentle slopes, while the harder limestones and sandstones form steep terraces and declivities. The surfaces of these hills, which stand up several hundred feet above the river, rapidly merge into a prairie plateau toward the west. The drainage

[a] The evolution of the northern part of the lowlands of southeastern Missouri: Univ. Missouri Stud., vol. 1, No. 3, 1902.

on the east is directly into the Mississippi. On the west, south of Salt River, it runs into streams that are more or less parallel with the uplift and, turning abruptly to the east just south of the anticline, enters the Mississippi.

Topographically, Missouri presents a considerable diversity, in striking contrast to those States which lie to the northeast, north, and west. The broad prairies of Illinois and Iowa and the plains of Nebraska meet in the northern half of this State. In the Ozark plateau and border is some of the most picturesque scenery to be found in the Mississippi basin, scenery that combines the most striking features of the mountainous regions of Kentucky, Tennessee, and Arkansas. In the southeastern lowlands are anticipated the broad coastal plains of the Southern States.

GEOLOGY.

ROCK FORMATIONS.

GENERAL STATEMENT.

The diversified topography of this State and the combination of features characteristic of surrounding States indicate a wide range of geologic horizons. In southeastern Missouri the oldest and the most recent formations are seen almost side by side.

The St. Francis Mountains were in the earliest Paleozoic period, the Cambrian, an archipelago of islands far distant from any other land of that primitive time. They formed a nucleus for the development of this portion of the continent.

The rocks of the State may be divided into the two groups, crystalline and sedimentary. The nomenclature of Missouri geologic formations has been heretofore in a very unsettled condition. Although this was one of the first States in the interior to establish a geological survey, later and more complete surveys have been made in surrounding States, with the result that many of the names first given to Missouri formations have had to be abandoned, for the reason that they were largely based on lithologic characters—a method of nomenclature no longer permissible. It is the intention in this report to give a brief résumé of the different formations of the State, emphasizing those which have an important relation to the water resources of the region under discussion.

Three of the five great eras of geologic history are represented in Missouri, viz, the Archean, Paleozoic, and Cenozoic; and while the rocks of the Mesozoic do not outcrop in the State, they are represented in deep-well sections in the southeast corner. The following table gives a list of the geologic formations, as complete as it is possible to make it at the present day. The writer is indebted to Dr. E. O. Ulrich for the synonymy of the Cambrian, Ordovician, Devonian, and Mississippian.

Geologic formations of Missouri.

System.	Series.	Group.	Formation.
Quaternary	Recent		Alluvium and residual soil.
	Pleistocene		Terrace gravel.
			Loess.
			Till.
			Columbia clay.
Tertiary	Pliocene		Lafayette gravel.
	Eocene		Lagrange formation.
			Porters Creek formation.
Cretaceous			Ripley sand.
Carboniferous	Pennsylvanian	Missouri	Undifferentiated.
		Des Moines	Pleasanton shale.
			Henrietta limestone.
			Cherokee shale.
	Mississippian	Chester	Graydon sandstone.
			Birdsville formation.
			Tribune limestone.
			Cypress sandstone.
			Ste. Genevieve limestone.
		Meramec	St. Louis limestone.
			Spergen limestone.
			Warsaw formation.
		Osage	Keokuk limestone.
			Burlington limestone.
		Kinderhook	Chouteau limestone.
			Hannibal formation.
			Louisiana limestone.
Devonian			Chattanooga shale.
			Callaway limestone.
			Clear Creek chert.
Silurian			Bailey limestone.
			Bainbridge limestone.
Ordovician			Girardeau limestone.
			Maquoketa shale.
			Polk Bayou limestone.
			Kimmswick limestone.
			Plattin limestone.
Cambro-Ordovician		Potosi	Joachim limestone.
			St. Peter sandstone.
			Jefferson City limestone.
			Roubidoux sandstone.
			Gasconade limestone.
			Elvins formation.
Cambrian			Bonneterre limestone.
			La Motte sandstone.
Archean			Iron Mountain porphyry.
			Knob Lick granite.

ARCHEAN.

The Archean rocks are confined entirely to the St. Francis Mountains in the southeastern part of the State. They consist of granites and porphyries, mainly the latter. About 700 or 800 feet of these rocks are exposed. They are the oldest in the Mississippi Valley, as well as in Missouri. Around this early land area are grouped in concentric bands the later geologic formations. The porphyries are usually found near the surface and the granites underneath, the two gradually merging into each other, indicating that they were probably formed from the same magma, their differences being largely due to the variation in the physical conditions under which they were formed.

These rocks outcrop in Madison, St. Francois, Iron, Washington, Wayne, Reynolds, Shannon, Carter, Ste. Genevieve, Butler, and Crawford counties. Keyes[a] classifies these crystalline rocks into

[a] Keyes, C. R., Report on Mine la Motte sheet; Missouri Geol. Survey, vol. 9, 1896, p. 19.

the Iron Mountain porphyry, 300 feet thick, and the Knob Lick granite, 400 feet thick.

Knob Lick granite.—This granite has its maximum development around Knob Lick, in St. Francois County. It is usually reddish in color, is composed mainly of quartz and feldspar, and is as a rule rather coarse grained. Biotite mica and hornblende are rarely present. It frequently weathers in characteristic rounded masses, well shown near the quarries at Arcadia.

Iron Mountain porphyry.—This rock is usually found capping the granite, except where it has been removed by erosion. The porphyries are more abundant on the west and the granites on the east of the Archean district. Haworth[a] has very fully described these rocks. He divides the porphyries into two great classes—the porphyries proper and the porphyrites. The first are made up of quartz and orthoclase, with microcline phenocrysts, the red variety having no phenocrysts. The second group includes those which have prominent phenocrysts composed of the varieties of triclinic feldspars, usually greenish in color, due to the minute dissemination of epidote crystals. As might be expected, springs are rare, and the water supply, as a rule, is poor in the granitic region.

Other igneous rocks.—Numerous dikes of basic eruptives are found, mainly of diabase, in the St. Francois region. These dikes vary from less than 1 inch up to 50 or 100 feet in width, and are usually vertical, or nearly so.

In Camden County, just south of the middle of the State, is an exceptional dike or boss of pegmatite, made up mainly of microcline feldspar, with some albite or oligoclase and numberless small masses of quartz. From this dike the strata dip in every direction. This is the only outcropping of igneous rocks, so far as known, outside of the district already described. For a fuller description of this locality the reader is referred to the paper by the writer on "The spring system of the Decaturville dome."[b]

CAMBRIAN.

The Cambrian rocks overlying the Archean are represented by the Bonneterre limestone, 500 feet thick, and the La Motte sandstone, 300 feet thick.

La Motte sandstone.—This sandstone, which usually surrounds the granite and porphyry outcrops, was first given the above name in the description of the mines at Mine la Motte. It probably has a total thickness, in the Archean area, of 200 to 300 feet. It is a soft, rather fine-grained, compact sandstone, cemented with calcareous

[a] Haworth, Erasmus. The crystalline rocks of Missouri: Missouri Geol. Survey, vol. 8, 1895.

[b] Contributions to the hydrology of the eastern United States, 1904: Water-Sup. and Irr. Paper No. 110, U. S. Geol. Survey, 1905, pp. 113-125.

and dolomitic material. It varies in color from white to ye brown, deep red, and purple, being usually darker where it come contact with the granite. The base of this sandstone is in many a coarse gravel or even a conglomerate of granite and prophyr bles. As a rule, this is a good water bearer, though the frequently carries iron. It is probably the source of some chalybeate springs of the district.

Bonneterre limestone.—The La Motte sandstone frequently by degrees, into the Bonneterre dolomitic limestone, which i the Fourth Magnesian limestone of Swallow, in part; the St. limestone, in part; the Fredericktown dolomite, in part, a Decaturville limestone. The Bonneterre has a thickness of 500 feet. The lower beds are usually a gray limestone, h there siliceous and in some places shaly. The upper bed yellowish dolomite, merging upward into thin-bedded an rocks. This formation is usually free from chert and is thus distinguishable from the distinctly cherty Gasconade limeston overlies it when the shaly Elvins formation is absent. Fo rare. One brachiopod, *Lingulella lamborni* Meek, and a fe Upper Cambrian forms have been found in the lower part.

CAMBRO-ORDOVICIAN.

The following formations are, for the present, grouped as un tiated Cambro-Ordovician beds: Joachim limestone, up to thick; St. Peter sandstone, up to 200 feet; Jefferson City lin 100 to 250 feet; Roubidoux sandstone, 100 to 225 feet; Ga limestone, 450 to 650 feet; Elvins formation, up to 150 feet.

Elvins formation. This formation (the basal part of the limestone of Nason) outcrops around the Bonneterre limeston St. Francis Mountains district. It is prevailingly shaly, espe its lower two-thirds. The basal part generally contains fro five or six thin bands of limestone conglomerate—the "e beds" of Nason. Locally the upper 60 feet or more con massive to thin-bedded, more or less earthy, noncherty d The formation is often wanting even in the southeastern min trict, and in such cases the cherty Gasconade limestone rests Bonneterre. These beds were also identified by Dr. E. O. U Camden County, around Pegmatite Hill, where they are ove a very coarse-grained, friable, reddish to yellow sandston formation has a maximum thickness of 150 feet.

Gasconade limestone. This formation includes the Fourth sian limestone, in part, and the Third sandstone of Swall Osage limestone and the Cole Camp sandstone of Winslow; t ter sandstone and the Proctor limestone of Ball and Smith, *Potosi limestone*, in part, of Nason. It has a thickness of fr

MATHERLY BLUFF, SAC RIVER, GREENE COUNTY.

Jefferson City limestone capped by St. Peter sandstone.

to 650 feet. It is made up of more or less heavy-bedded limestones, which in many places merge into dolomite, and may contain nodular, disseminated, or thin-bedded chert. Here and there are irregular lenses of sandstone, and the writer believes he has found throughout the State a well-defined and persistent bed of sandstone—the Third sandstone of Swallow. The Gasconade limestone is widely distributed throughout the southeastern quarter of the State, around the Archean rocks. A long strip of it extends through Texas, Pulaski, Phelps, and Maries counties. Another strip extends northeastward through Dallas, Camden, Morgan, and Miller counties, and narrow strips outcrop along some of the streams that run through Douglas and Ozark counties. This formation is an important water bearer, as is shown by the great springs that issue from its cavernous beds.

Roubidoux sandstone.—This formation includes the Second sandstone of Swallow, the Moreau sandstone of Winslow, and the Bolin Creek member of the St. Elizabeth formation of Ball and Smith. It is from 100 to 225 feet thick. The sandstone of this formation is made up of waterworn, well-rounded grains of quartz, and varies in color from white to yellow, reddish, or almost black, according to the amount of iron that it contains. Much of it exhibits false bedding, ripple marks, and sun cracks. It varies in thickness, but the writer has found it remarkably persistent and outcropping above the exposures of the Gasconade limestone. It is somewhat porous, though locally cemented with silica into a compact mass. It is a prominent water horizon in the counties mentioned in the preceding paragraph as containing the Gasconade limestone, and is the reservoir source of most of the large springs of the southeastern part of the State.

Jefferson City limestone.—This formation, which is from 100 to 400 feet thick, is equivalent to the Second Magnesian limestone of Swallow and the Winfield limestone of Keyes. It is a dolomitic limestone, usually more or less heavy bedded, rather soft when freshly broken, fine grained, compact, and grayish white. Locally, especially in its upper part, it is thin bedded. Most or all of the upper thin-bedded part is rather generally absent in Missouri, having been removed by erosion prior to the deposition of the Devonian and Carboniferous rocks which, especially in the southwestern part of the State, generally overlie this formation. The remaining lower beds are highly siliceous, and frequently, in weathering, exhibit jagged honeycombed peaks or block-like masses (Pl. II). They are also frequently pitted with geode-like cavities. When honeycombed by weathering they leave siliceous skeletons in strangely contorted forms, and many hillsides underlain by this formation are abundantly covered with chert. Here and there beds of thin sandstone are found near the middle of this formation. In the mining districts it is not unusual to find

intercalated beds of thin variegated blue and white shale, call the miners "the soapstone layer." It is very probable tha the chert and the siliceous beds are usually examples of replac of limestone by percolating waters holding silica in solution.[a]

The Jefferson City limestone has a wide distribution throu the Ozarks.[b] It varies decidedly in thickness, probably reac maximum of nearly 400 feet in the Lebanon deep well, wi miles to the south, in the Metropolitan deep well at Springf seems to be but 90 feet thick. The porous beds of this for are the source of some of the smaller springs of the Ozarks.

St. Peter sandstone.[b]—This formation is the equivalent of th or Saccharoidal sandstone of Swallow, the Cap au Grès sands Keyes, the Pacific sandstone of Ball and Smith, the Cryst sandstone of Winslow, and in part the Key sandstone of The Marshfield sandstone and the Bolivar sandstone of southw Missouri are commonly believed to represent the same formati Ulrich regards them as lenses within the Jefferson City lim Ulrich maintains further that the true St. Peter sandstone is or never present when late Devonian or Carboniferous rocks contact with the Cambro-Ordovician.

This formation is the most important water bearer in the north of Missouri and one of the most important in this Sta has a thickness of 10 to 200 feet and is brought to the sur Ralls and Lincoln counties and in some of the counties n Missouri River to a point nearly halfway across the State. outcrops in the counties just west of Mississippi River and s St. Louis County. Its presence to the west and southwest Ozarks is doubted by some geologists, but, although it may n to the surface, the writer believes that it occurs under e around the Ozark Island in Missouri. It is a rock that f prominent landmark in the correlation of the different horiz is made up of highly polished, rounded, waterworn grains of to translucent quartz, rather loosely cemented together. Wh generally somewhat friable, it seems to possess to a high de power to resist the elements. Its durability is exhibited manner in which it stands out in ledges and forms bend overhanging shelves in the bluffs along streams. It varies from white to a yellowish brown or red, the coloration being due to iron, which commonly forms part of the cementing m but does not affect the grains.

This sandstone is remarkably persistent and covers a lar The water yielded by it is usually pure and soft when i

[a] See Shepard, E. M., Spring system of the Decaturville dome, Camden County, Mo. West Irr. Paper No. 110, U. S. Geol. Survey, 1905, p. 124.

[b] The Jefferson City and St. Peter formations cover smaller areas than those shown The St. Peter, in the western and southern areas shown, contains many bodies of younger

percolated through the formation for long distances. Here and there minute particles of marcasite are found, which tend to impregnate the water with sulphur and iron.

Joachim limestone.—This formation is the equivalent of the First Magnesian limestone of Swallow, the Folley limestone of Keyes, and probably of the Finley limestone of the writer. It varies greatly in thickness, ranging from a knife edge to 125 feet. Its distribution corresponds somewhat to that of the St. Peter sandstone. It is generally a thin, evenly bedded, fine-grained, compact dolomitic limestone, varying from white to yellowish in color; much of it is so soft and white as to be called "cotton rock." The upper beds are locally silico-magnesian in character and so uneven in texture that in weathering the softer portions are worn away, leaving an irregularly pitted surface.

ORDOVICIAN.

According to the prevailing definition of the Ordovician, this system should include the formations between the top of the Girardeau limestone and the base of the Jefferson City limestone, the latter being, as interpreted by Ulrich, equivalent to the Beekmantown or Calciferous rocks of New York. Indeed, according to Ulrich, the lower limit of the Ordovician might be extended downward to the base of the Gasonade without serious modification of the present conception of the Cambrian. However, for reasons that need not be stated here, it has seemed wise to the writer to place in the Ordovician only those formations about which there can be no doubt, and to refer the underlying rocks down to the top of the Bonneterre limestone, provisionally to a "Cambro-Ordovician" system. The Ordovician, then, includes the following: Girardeau limestone, up to 50 feet thick; Maquoketa shale, up to 40 feet; Polk Bayou limestone, 1 to 3 feet; Kimmswick limestone, 40 to 90 feet; Plattin limestone, 100 to 200 feet. These Ordovician rocks are almost wholly confined to the eastern part of the State, south of Hannibal; except the Maquoketa shale and Kimmswick limestone, they are rarely found in well sections to the northwest and southwest. They are of little importance as water carriers and have so limited a distribution that it will be unnecessary, so far as the purpose of this report is concerned, to give them further attention.

SILURIAN.

The Silurian rocks, like the Ordovician, have a somewhat limited range throughout the State. They are confined mainly to the few counties south of St. Louis, but extend westward for a short distance along Missouri River. In only a few cases, near the areas of outcrop,

has it been possible to recognize them in well sections. They consist of the Bailey limestone, 70 to 150 feet thick, and the Bainbridge limestone, up to 125 feet.

For the same reasons as those given in connection with the Ordovician, it will not be necessary to consider the Silurian rocks further.

DEVONIAN.

The Devonian rocks form a very narrow penumbral margin around the Ozark Island. Except in the counties south of St. Louis and along Missouri River, the beds are very thin, irregularly distributed, and of little or no importance from the standpoint of water supply. The different formations are the Chattanooga or Ohio shale, up to 30 feet thick; Callaway limestone, up to 50 feet; Clear Creek chert, up to 150 feet.

The Callaway limestone north of St. Louis is in part the equivalent of the Chattanooga shale, and south of St. Louis of the upper part of the Grand Tower limestone.

CARBONIFEROUS.

MISSISSIPPIAN.

The Mississippian series of the Carboniferous bears a most important relation to the water resources of Missouri. It forms a broad belt running in an irregular diagonal across the State from southwest to northeast and a very narrow strip southward from the mouth of Missouri River along the banks of the Mississippi to Cape Girardeau County. The following formations are comprised in the Mississippian: Birdsville formation, up to 300 feet thick; Tribune limestone, 100–150 feet; Cypress sandstone, 50–100 feet; Ste. Genevieve limestone, 150–150 feet; St. Louis limestone, 300 feet; Spergen limestone, 100 feet; Warsaw formation, up to 50 feet; Keokuk limestone, 200 feet; Burlington limestone, 300 feet; Chouteau limestone, 70 feet; Hannibal formation, 30–100 feet; Louisiana limestone and equivalent formations, up to 100 feet.

Louisiana limestone.—This is the equivalent of the Lithographic limestone of Swallow, who named it for its supposed lithographic qualities, which, however, were never realized in this State. So far as the writer has observed, it reaches its maximum thickness, 100 feet, at Louisiana and the best exposures are found along Mississippi River between Louisiana and Hannibal. In this region it is a fine-grained, compact, thin-bedded, dolomitic limestone, usually ash colored. It is generally underlain by a sandy shale, which is more or less fossiliferous. It thins out and becomes coarse grained elsewhere in the State. In the counties west of Pike it is much thinner, is coarser grained, and has a slightly bluish tinge. It has been recognized in Cedar and St.

Clair counties, and Swallow found 30 feet of it in Jasper County. In Greene and Webster counties the Hannibal formation is underlain by four thin but lithologically distinguishable beds that are regarded by Ulrich as representing the Louisiana limestone. The uppermost of these beds has long been correlated with that limestone by the writer. It is widely distributed in the southwestern part of the State, ranges from 8 to 22 feet in thickness, and is so compact in texture as to ring like bell metal when struck. The other beds are much more local in their distribution. They were described by the writer, who called them Phelps sandstone, King limestone, and Sac limestone of the Hamilton stage (Devonian). Few fossils are found in these beds, though the weathered surfaces expose depauperate forms of crinoid stems.

Hannibal formation.—This is the equivalent of the Vermicular sandstones and shales of Swallow. It is from 30 to 150 feet thick. In the type locality, in Marion County, this formation consists of beds of bluish to greenish argillaceous shale, frequently calcareous or dolomitic, with impure layers of limestone or dolomite. The rocks vary greatly in composition, containing a number of mineral salts which tend to impregnate the water. Many of the strongest mineral waters have their source in this formation. It is somewhat widely distributed throughout the State, becoming more calcareous to the west of Marion County and represented by several distinct rocks in the southwest and south. For example, in Greene, Polk, Lawrence, and Webster counties it consists in many places of three members. In northern Greene and Polk counties is found a heavy deposit of fine-grained buff sandstone, penetrated everywhere by worm-like borings that are filled with less indurated matter. This sandstone is fairly durable, and in weathering usually forms benches or terraces. It graduates through beds that become less and less arenaceous into compact silico-magnesian shales. These shales are usually grayish to blue, but locally greenish. In many places they are shattered and the veins are filled with a white, soft substance, like kaolin. The shales and sandstones locally exhibit cauda-galli markings and, near their contact, nodular elliptical masses of impure iron pyrites are found. On the south side of the Ozark dome, the watershed that extends through Greene County, the sandstone gradually disappears and the shale predominates. Farther south, in adjoining counties, the shale merges into an impure limestone. It is uncertain whether these rocks occur in southeastern Missouri. Some variegated clay shales below the Burlington limestone in Ste. Genevieve County have been doubtfully assigned to this formation.

A more extended account of this horizon has been given than its distribution would justify, because it is one of the most important in its relation to underground waters. It contains a large proportion of

impurities and is the source of some of the strongest mineral waters of the State.

Chouteau limestone.—This peculiar buff to dark-yellow rock received its name from Chouteau Springs, in Cooper County, being first described by Swallow. In color and texture the rock throughout the State varies greatly from that at the type locality, where it is ashy gray in appearance and of the nature of a shaly limestone. In Marion and Pike counties it is from 10 to 15 feet thick, buff colored, and somewhat arenaceous. In Pettis County it reaches a thickness of 100 feet. In Webster County it is about 40 feet thick. In the southwest it is usually heavy bedded, hard, and compact, and in many places very arenaceous. The beds generally contain small, geode-like cavities lined with minute calcite crystals. Here and there crystals of pyrites are disseminated through the rock, and some chert is also found in the southwest. The rock indurates on exposure, and this fact, together with its striking color, causes it to form a noticeable topographic feature. The Chouteau is usually too compact to be counted as a water carrier, yet in places springs of somewhat mineralized water rise from fissures in it. As a rule the Chouteau forms a more or less impervious bed beneath the Burlington limestone.

Burlington limestone.—This formation is usually a coarse-grained, highly crystalline, and very pure limestone. It varies considerably in thickness and in other characteristics in different parts of the State. It has a rather wide distribution in the counties bordering the Mississippi on the west, extending in an irregular diagonal to the southwest corner of the State, where it covers a broad area. In the southwest it has two distinct parts—the upper and the lower. Here the upper bed is usually from 200 to 300 feet thick and similar in fauna and structure to the beds in the northern part of the State, while the lower bed, which is much less persistent, varies from 20 to 60 feet in thickness and consists of a very dense, hard, and impure rock that has a bluish slate color and breaks with a conchoidal fracture. The fossils of the lower bed are much smaller than those of the upper, the crinoids in particular being of the more delicate varieties, in strong contrast with the large robust forms of the upper bed.

Between these two Burlington beds is a transition layer of chert, varying from 5 to 40 feet in thickness. This chert is usually seamed, shattered, and irregularly bedded, very hard, compact, and white. The intercalated chert of the upper part of the Burlington is very soft, impure, and fossiliferous, of reddish shades of color, and usually disposed in lens-shaped masses. Where the lower bed of the Burlington is present, the intervening shattered chert is the source of many large, fine springs, the water having been derived from the upper bed, which is one of the great water carriers of the State. It is very probable that

A. BLUFF OF BURLINGTON LIMESTONE NEAR JUNCTION OF SHOAL RIVER AND CAPS CREEK.

B. CHARACTERISTIC WEATHERING OF GRAYDON SANDSTONE AT EUDORA SPRINGS, POLK COUNTY.

this transition chert has been formed by replacement of the original limestone through the action of the large quantities of siliceous waters that are constantly passing through the upper bed of this formation.

Topographically, the upper part of the Burlington is marked everywhere by the presence of large sink holes, and it forms the largest and most important basin and reservoir for collecting water in the State. As the limestone is very pure and porous and the intercalated chert impure and soft, percolating waters dissolve out large quantities of lime and silica from the chert and, encountering the impervious lower Burlington or Chouteau below, issue in the valleys as great springs.

This formation is honeycombed with great caves in which flow underground streams. It also forms striking topographic features in the mural and castellated bluffs along the great rivers in the region where it outcrops. (See Pl. III, *A*.)

Keokuk limestone.—This limestone, which is largely distributed over Illinois, is represented in Missouri mainly in the northeastern part. It is about 200 feet thick and made up of rather compact layers of bluish limestone at the base of the formation, varying with shaly masses intercalated with thinner beds of limestone above. Its presence south of Missouri River is disputed. The fauna of the Burlington and overlying beds in the southwest seems to be a mixture of Keokuk and Burlington types, so much so that other names, such as Cherokee and Encrinital have been proposed for these transition beds. It is probable that most of the upper Mississippian is absent in the southwestern part of the State, the Pennsylvanian deposits resting unconformably upon the Burlington at various points in that region. The Keokuk is not a prominent water carrier in Missouri.

Warsaw formation.—This formation, confined mainly to the northeastern part of the State, is problematic in its relations. It is described by Hall[a] as being made up, near Keokuk, of magnesian limestone of variable thickness, which is in places absent, overlain by argillaceous limestone with shaly partings, followed by coarse calcareous yellow sandstone in thick heavy beds. Some authors include it with the Keokuk and others with the St. Louis. Ulrich regards it as a distinct formation overlying the Keokuk and forming the basal division of his Meramec group. (See table of formations, p. 12.) The Warsaw is of very little importance as a water bearer in Missouri.

Spergen limestone.—This formation is confined in Missouri to the counties bordering the Mississippi below the mouth of Missouri River. Here, as in the States to the east and southeast, it consists chiefly of massive oolitic limestone, parts of which afford a handsome building material. In St. Louis County its thickness is about 100 feet, but in Ste. Genevieve and Perry counties it seems to be not less than 200 feet.

[a] Hall, James, Geology of Iowa, vol. 1, 1858, p. 101.

So far as known the Spergen limestone has no special connection with the water problems of the State.

St. Louis limestone.—This formation is well developed along the Mississippi from Iowa to Cape Girardeau County. Keyes describes it as being more or less brecciated to the north of St. Louis County, while south of Missouri River it is an evenly bedded, cherty gray limestone. It reaches a considerable thickness, the maximum development within the State being nearly 300 feet. While more largely developed than some other formations, it is not an important water bearer.

Chester group.—The formations belonging to the Chester group have so small a distribution in Missouri that they will not be considered separately in this report except to state that good water is usually obtained from the Cypress sandstone and the Ste. Genevieve limestone. The group consists of the Birdsville formation, up to 300 feet thick; Tribune limestone, 100–150 feet; Cypress sandstone, 50–100 feet; and Ste. Genevieve limestone, 100–150 feet.

PENNSYLVANIAN.

The Pennsylvanian series of the Carboniferous is divided into two groups—the Des Moines and the Missouri.

DES MOINES GROUP.

One of the most important sources of water supply is in the basal formations of the Des Moines, which is represented by the Pleasanton shale, up to 200 feet thick; Henrietta limestone, up to 100 feet; Cherokee shale, up to 300 feet; and Graydon sandstone, up to 75 feet.

Graydon sandstone.—This formation consists of several members, the most prominent of which is a coarse-grained, friable, usually micaceous, ferruginous sandstone, with scattering intercalated patches or beds of highly inclined shales, from blue to greenish black in color and in many places mixed with thin seams of carbonaceous matter. Its thickness ranges from a feather edge to 75 feet. The sandstone locally merges into a fine to coarse cemented gravel, and finally into a coarse, polished bowlder conglomerate. This formation seems to fill old erosion channels or basins and is almost invariably tilted and unconformable to the beds upon which it rests. It probably marks the beginning of the submergence which resulted in the deposition of the Pennsylvanian rocks. It apparently skirts the Ozark Island and has been traced from Fulton, Callaway County, where it is finely exhibited in a bluff on the outskirts of the town, down to southern Missouri. Its best development is perhaps in Cedar, Polk, Dade, Lawrence, Greene, and Christian counties. Ball and Smith[a] have described a number of interesting outcroppings in Miller

[a] Ball, S. H., and Smith, C. F., Geology of Miller County: Rept. Missouri Bureau Geology and Mines, 2d ser., vol. 1, 1903, p. 95.

County, some distance from the borders of the coal field, where it is most commonly exhibited. (See Pl. III, *B*.)

This sandstone is an important water bearer, many of the most valuable chalybeate springs of the State having their origin in it. A number of so-called sulphur springs come from this formation, but owe their apparent sulphurous odor to minute traces of petroleum derived from the intercalated carbonaceous shales.

Cherokee shale.—The Cherokee shale is a very important formation in Missouri, being the source of practically all the workable coal, gas, and oil. From it also are obtained most of the brines and sulphosaline waters. The formation was named by Haworth from Cherokee County, Kans., where it is particularly well developed. It is made up largely of sandstones and shales, the shale members being perhaps the more persistent. The sandstone is usually more abundant at the base of the formation. Besides numerous coal seams a few thin beds of limestone occur. These are usually restricted in area and are in many places fossiliferous and carbonaceous. Some of the most interesting problems connected with the water supply of the State arise from the study of this formation.

The Cherokee shale is distributed in an irregular diagonal strip, forming an outside border to the Mississippian rocks from the southwestern part of the State through to the northeast corner. These rocks dip strongly to the northwest at the rate of from 10 to 20 feet to the mile, and their thickness varies considerably, being in some places 300 feet.

Henrietta limestone.—The Henrietta limestone is a composite formation somewhat like the Cherokee shale and is made up of arenaceous shales and thin beds of sandstone and limestone. In places it is 100 feet thick. The name was given by Marbut to the associated beds with the limestone members, which, though thinner than the shales and sandstones, form escarpments that run through the State, making pronounced topographic features.

The limestone members are essentially the extension of the Pawnee and Fort Scott limestones of the Kansas Survey. The formation may be traced from Bates County, on the Kansas line, to Missouri River in Lafayette County and for some distance north of the river. It is not an important water bearer, there being no springs of any size along its course; but a small supply of water is obtained by sinking wells to the limestone beds.

Pleasanton shale.—This is the equivalent of Marbut's Marais des Cygnes shale. The formation is made up of argillaceous and arenaceous shales, some sandstones, and several small veins of coal. It forms a belt 15 or 20 miles wide, extending from Bates County, on the Kansas line, to Lafayette County, where it crosses the river and passes on northward through the State. Springs are rare in this

formation. Wells sunk to the sandstone or limestone beds usually give a fair amount of water.

MISSOURI GROUP.

The Missouri, the uppermost group of the Carboniferous rocks, is usually made up of heavy alternating beds of shales, limestones, and sandstones, the shales largely predominating. No good supplies of water are found in the 1,000 feet of this formation, that obtained being usually saline and in many cases strongly impregnated with other mineral salts.

The beds of the Missouri group are confined to the northwest quarter of the State. The lowest forms an escarpment extending from southern Cass County northward through Mercer County into Iowa.

CRETACEOUS.

While the Cretaceous rocks nowhere outcrop within the limits of the State, they undoubtedly extended up the Mississippi embayment a short distance into Missouri and were subsequently covered by Tertiary deposits. A number of deep wells in the embayment area of Missouri and the adjoining portions of Tennessee and Kentucky penetrate, at varying depths, loose sand and clay which, from their situation and structural characters, are probably the equivalent of the Ripley sand. These sand beds are usually nonfossiliferous, but in many places contain fragmentary particles of lignite. They vary in color from white to black, but are more commonly red or yellow, owing to the presence of iron. They are from 25 to 50 feet thick in well sections at Cairo, Ill., and 224 feet thick in the well at Morehouse, where they are reached at a depth of 466 feet. In the Campbell artesian well, at a depth of 940 feet, a very fine black sand with a large percentage of mica in small pieces was struck. The boring penetrated 20 feet of this material and stopped at a depth of 960 feet. The Ripley sand is a water bearer and has a thickness of 400 feet in southern Tennessee.

TERTIARY.

The Tertiary rocks outcrop in the extreme southeast corner of the State, where they fill the old valley of Mississippi River.

Porters Creek formation.—Lying above the Ripley sand of the Cretaceous, as already described, is the Porters Creek formation—probably of Eocene age. This consists of a loose, green sand or clay at the base, with scattered beds from 1 to 4 feet thick of indurated calcareous green sand or impure limestone, and a few layers of fine micaceous sandstone. The clay is usually dark when wet

and a light gray when dry. Safford gives its thickness as from 200 to 300 feet in Tennessee. Glenn states that it is not there a bearer of good water. It forms, however, an impervious layer over the waters of the Ripley sand. It has been identified in Missouri wells at but one point. It was reached in the Morehouse well at a depth of 248 feet, where is consisted of 197 feet of bluish gumbo.

Lagrange formation.—Overlying the Porters Creek formation is the Lagrange formation. This consists of great masses of loose sand intercalated with beds or lenses of blue clay. It varies greatly in thickness, being 963 feet at Memphis, Tenn.; 785 at Campbell; 740 at Hickman, Ky.; 542 at Caruthersville, and over 200 feet at Morehouse. The only fossils found are imperfect leaf impressions. Those in the lower beds are believed to be Eocene, while those in the upper are probably Pliocene. Authorities are, however, inclined to consider this as one formation. It includes the Lagrange and Bluff of Safford. It is the great water reservoir for the artesian and deep wells of this district.

Lafayette gravel.—Above the Lagrange rests the thin bed of the Lafayette. This varies from 10 to 60 feet in thickness. Along the bluffs of the larger streams a basal deposit of cemented gravel is found. This congiomerate is made up of rounded, waterworn, and polished chert pebbles which are apparently glazed with a yellow iron stain. Percolating waters charged with iron have cemented these pebbles near the rivers into a hard ferruginous conglomerate. Small chalybeate springs are not uncommon along this deposit. Away from the larger streams the gravel is less abundant, not cemented, and gradually merges into an orange-colored sand and irregular deposits of clay. This is the equivalent of Saffords Bluff gravel and, in part, of his Orange sand.

QUATERNARY.

Columbia clay.—Upon the Lafayette gravel rests the Columbia, at the base of which, along the bluffs, is usually found from 10 to 15 feet of sand and gravel. Above this deposit is from 20 to 60 feet of loess, which is in turn overlain by a varying amount of loam. Crowleys Ridge and its continuation, Benton Ridge, show fine sections of the Columbia and Lafayette.

Alluvium, etc.—Irregularly distributed over the flood plain of the Mississippi are later deposits than the Columbia—the Recent alluvium, which overlies the Columbia clay, and large patches of sand, of varying thickness, which has all the structural and microscopical characteristics of the Lagrange formation, and has probably been thrown up through the fissures caused by the New Madrid earthquake.

GEOLOGIC HISTORY.

Before closing this section, a brief outline of the geologic history of the State should be given, as that history is of considerable importance in its bearing on the location of artesian areas, the varying chemical composition of the waters, and a more complete understanding of the many and varied topographic and geologic features. While it is not possible, in all cases, to give the correct sequence of events, and while some conclusions may be modified by wider study of this region, it seems desirable to present an outline that is sustained by the facts now available. Winslow, Broadhead, and Buckley have each given such a history in brief, and they have been freely consulted in the preparation of this sketch.

ARCHEAN.

During Archean time a large part of Missouri and extensive portions of the continent to the north and south of this State were dry land. It is impossible, at present, to outline the extent of this area. The erosion must have been great and the time long, to have sufficed for the accumulations of the succeeding age. The few isolated peaks in the St. Francis Mountains are all that is left to-day of this original land area in Missouri. It is doubtful if there are any Algonkian rocks in this State. A general submergence of a large part of the area brought in the Cambrian.

CAMBRIAN AND CAMBRO-ORDOVICIAN.

These ages are represented by coarse sandstones and conglomerates forming narrow fringes around the small islands now represented by the Archean outcrops in the St. Francis Mountains. These shore deposits were, at first, largely of fragmental origin, but in the quieter waters around the archipelago alternating deposits of limestones and sandstones, indicating periods of elevation and depression, with occasional erosion intervals, were laid down. It is probable that the nucleus of this varying land surface was an area around the St. Francis Mountains. It is generally believed that at the close of the deposition of the Jefferson City limestone a large area was elevated and a somewhat extended erosion period began. This was followed by a submergence, during which the St. Peter sandstone was laid down. It is doubted, by many, whether this submergence extended over the whole of what now constitutes the Ozarks or not. At any rate, the St. Peter sandstone practically surrounds the Ozarks in Missouri; but whether it covered the larger portion and has been subsequently removed by erosion or whether it formed only an off-

shore deposit around Ozarkia[a] is a question that, with the data now obtainable, can not yet be decided. A considerable elevation took place just preceding the Ordovician period.

ORDOVICIAN.

There is also a doubt as to the former extension of the "Trenton" and other typical Ordovician rocks in the Ozarks. Like the St. Peter sandstone, they may have been deposited over a much larger area, from which they were removed by subsequent erosion, or their limits may always have been, practically, what they are to-day. The determination by Ulrich of a small patch of cherty Maquoketa shale in Camden County, far in the interior of the Ozarks, would indicate a wider distribution of at least the latest of the Ordovician formations than has heretofore been supposed. There is strong evidence that south of Missouri River there was a very large land area during the most of Ordovician time. Small deposits of this age are found east of the St. Francis Mountains and along Mississippi River northward toward Iowa. They also extend, to a limited degree, along an embayment now occupied by Missouri River.

SILURIAN AND DEVONIAN.

With slight modifications, the conditions prevailing during the Ordovician continued through the whole of Silurian and the greater part of Devonian time. Toward the close of the Devonian a gradual embayment of Ozarkia set in that culminated in the early part of the Carboniferous. Silurian deposits occur only along the Mississippi in Perry and Cape Girardeau counties. Devonian sediments are also but sparingly represented in the State. Thin beds of Devonian limestone and shale are found north of St. Louis and along Missouri River, while local deposits of the blue Chattanooga shale have been noted on the southwestern flanks of the Ozark uplift.

CARBONIFEROUS.

The close of the Devonian was marked by a considerable depression west of the Mississippi in the northern part of the State and along the slopes of the Ozarks to the west. The ocean invaded the Ozarks, forming a considerable embayment in what is now Green County, penetrating the western slopes so as to form many patches lying unconformably on the Cambro-Ordovician. This subsidence was

[a] The term "Ozarkia" is a convenient name proposed by Ulrich (Prof. Paper, U. S. Geol. Survey No. 24, 1904, p. 111) for the ancient land mass that at various times during the Paleozoic era formed a large island or groups of small islands in the area of southern Missouri and northern Arkansas now exposing the Cambrian and Cambro-Ordovician rocks. In a measure, the term is an alternative for "Ozark uplift," "Ozark dome," or "Ozark Island."

rapid at first, during which time deposits of coarse materi as the "Phelps" and Hannibal sandstones and shales and the Chouteau limestones, were laid down. The depauperate form Hannibal and Chouteau fossils indicate rather impure wat sibly brackish in places. This condition was followed by depression and by deeper and purer waters and the depositi cessively, of the Burlington and Keokuk in the southwest, w northwest; to the east and northeast these were followed, by the Warsaw, Spergen, St. Louis, Ste. Genevieve, and ot stones of the Mississippian. Most of these heavy beds of l are rich with fossil forms. From the fact that small patch Burlington, together with its chert, are found scattered as fa Texas and Howell counties, it is probable that the Springfiel ment reached these points. The greater part of the Oz remained above water since Burlington time.

Toward the close of the Mississippian the great ocean flo west was slowly elevated, becoming a nearly level area, cov marshes and estuaries. This movement was apparently panied by a slight depression in the region now included and Morgan counties, which permitted the formation of pockets now found lying uncomformably in erosion basin Cambro-Ordovician rocks. Along this low-lying land, in o and estuaries, conditions were favorable for the develo great swamps in which were accumulated the extensiv of coal characteristic of the Pennsylvanian period. It w this depression that some of the great rivers which dr Ozarks were filled up by sands and gravels. Where emptied into estuaries, large deposits of conglomerates are is well illustrated by the ancient Schoolcraft River, which from Arkansas through Stone, Christian, Greene, and P ties, and in which the Graydon sandstone and conglome laid down. That the extent of the Pennsylvanian rocks w than at present is shown by the number of outliers in th coal pockets scattered over the adjoining counties and resti formably upon other terranes.

This period, while one of gentle oscillations, was yet, on t one of steady depression, being characterized by the dep thick alternating beds of limestones, shales, and sandstones.

The close of the Paleozoic, which was brought about in by the Appalachian revolution, was manifested in Miss bulging up of the Ozarks, a great dome, or quaquaversal i thereby formed.

MESOZOIC.

With the exception of the small deposit of Ripley san *Mississippi* embayment, reached by deep drilled wells, the

which followed the Carboniferous, has no representative in this State. It was probably a period of erosion and land sculpturing.

TERTIARY.

During the early Tertiary the Lafayette (Winoka) gravel, which is represented in scattered patches high up above the present river courses, was deposited. These gravels mark the outline of early Tertiary drainage systems. The elevation of the great Mesozoic deposits west and southwest of Missouri extended into this State, changing the direction of the drainage systems and developing, probably for the first time, Missouri River, the source of which seems to have been not far beyond the northern boundary of the State.

QUATERNARY.

During Pleistocene time the northern part of the State, approximately bounded by Missouri River, was covered with the drift of the Pleistocene, which, in some places, reached a thickness of nearly 300 feet. The general southward movement of the ice sheet greatly modified the surface of this part of the State, eroding large areas and filling up old channels. Since Pleistocene time this area has been subjected to the erosive action of the elements. Deep valleys have been formed and the more porous rocks have been honeycombed by numerous channels, forming underground streams and the outlets of the great springs which characterize this State.

DESCRIPTIONS OF GEOLOGIC SECTIONS.

SECTION FROM GLENWOOD, IOWA, TO BRUNSWICK, MO.

Well sections in the northwestern part of the State show a deep depression or trough extending in a southwesterly direction from Iowa through Missouri and into Kansas. Section 1 (Pl. IV) is taken approximately at right angles to this depression in order to show the development of the trough. Norton[a] gives the following record of the well at Glenwood, Iowa, 2,000 feet deep:

Summary of log of well at Glenwood, Iowa.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	175	175
Missouri	670	845
Des Moines	390	1,235
Mississippian	230	1,465
Devonian (?)	135	1,600
Silurian	400	2,000
Maquoketa (?)		2,000

[a] Norton, W. H., Artesian wells of Iowa: Geol. Survey Iowa, vol. 6, 1897, p. 347.

This well was sunk for oil.

A diamond-drill well, sunk to a depth of 500 fe
Gentry County, struck a bed of coal 26 inches thick
feet. At the farm of G. H. Lawson, near Utica,[a] L
a well was sunk to a depth of 421 feet, at which p
limestone was struck. In a well on the farm of J
south of Dawn, in the same county, the Mississippi
433 feet.

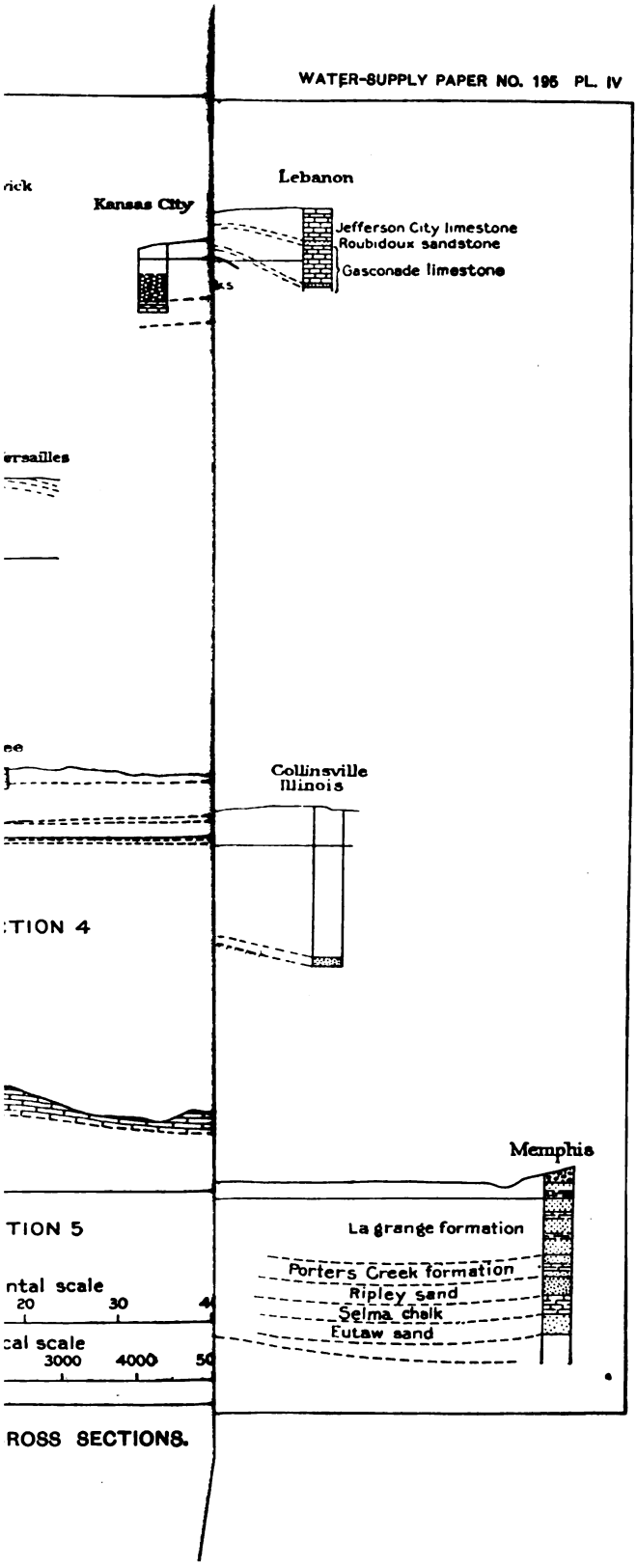
At Chillicothe, just north of the two points last
same county, the following section was obtained; p
rocks might also be found at Utica and Dawn:

Summary of log of well at Chillicothe.

Pleistocene	
Des Moines	
Mississippian, Devonian, and Silurian	

There is, probably, 100 feet of St. Peter sandstone
this well.

The well at the creamery near Hale, Carroll Count
290 feet of Des Moines and 40 feet of Mississippian,
330 feet.



ROSS SECTIONS.

Well No. 1 of the Nodaway Valley Oil, Gas and Mineral Company, at Burlington Junction, Nodaway County, 1,903 feet deep, has the following record:

Summary of log of well at Burlington Junction.

	Thickness	Depth
	Feet.	Feet.
Pleistocene	68[illegible]	[illegible]
Missouri	919	[illegible]
Des Moines	722	[illegible]
Mississippian	186	[illegible]

This well was sunk for oil.

A diamond-drill well, sunk to a depth of 500 feet at Gentryville, Gentry County, struck a bed of coal 26 inches thick at a depth of 477 feet. At the farm of G. H. Lawson, near Utica,[a] Livingston County, a well was sunk to a depth of 421 feet, at which point Mississippian limestone was struck. In a well on the farm of John R. Williams, south of Dawn, in the same county, the Mississippian was reached at 433 feet.

At Chillicothe, just north of the two points last named and in the same county, the following section was obtained; probably the same rocks might also be found at Utica and Dawn:

Summary of log of well at Chillicothe.

	Thickness	Depth
	Feet.	Feet.
Pleistocene	[illegible]	[illegible]
Des Moines	[illegible]	[illegible]
Mississippian, Devonian, and Silurian	[illegible]	[illegible]

There is, probably, 100 feet of St. Peter sandstone at the bottom of this well.

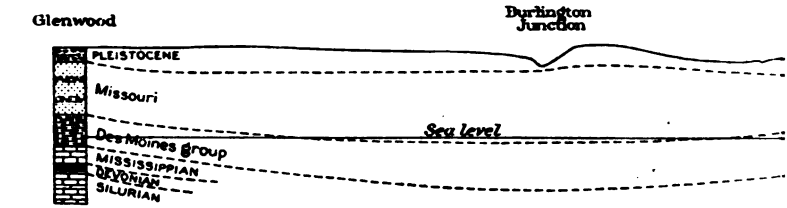
The well at the creamery near Hale, Carroll County, passed through 290 feet of Des Moines and 40 feet of Mississippian, giving a depth of 330 feet.

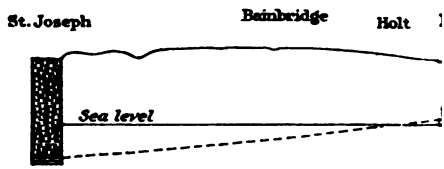
At the C. W. Nuss well, at Tina, Carroll County, the following section was obtained:

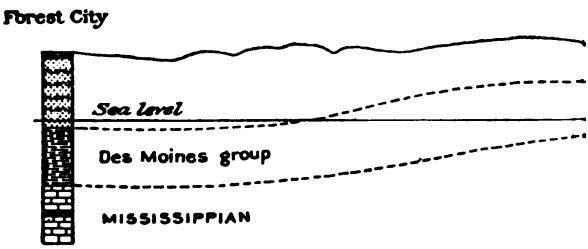
Summary of log of well at Tina.

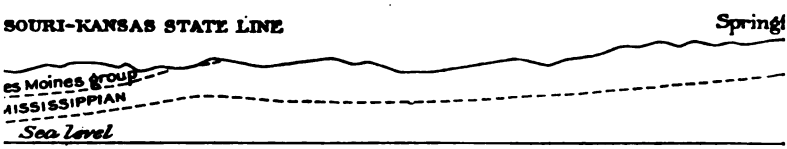
	Thickness	Depth
	Feet.	Feet.
Pleistocene	[illegible]	[illegible]
Des Moines	[illegible]	[illegible]
Mississippian	[illegible]	[illegible]

[a] Data in regard to the wells at Utica, Dawn, Hale, and Tina were obtained through the [illegible] Mr. R. Hawkins of Chillicothe, to whom the [illegible] is indebted for a large amount of information concerning the wells of the northern part of the State.


Glenwood
Burlington Junction
PLEISTOCENE
Missouri
Sea level
Des Moines group
MISSISSIPPIAN
DEVONIAN
SILURIAN


St. Joseph
Bainbridge
Holt
Sea level


Forest City
Sea level
Des Moines group
MISSISSIPPIAN


SOURI-KANSAS STATE LINE
Springf
es Moines group
ISSISSIPPIAN
Sea level

At Brunswick, Chariton County, a drill hole was sunk to a depth of 1,505 feet. Unfortunately the record is not obtainable, but it is said that 130 feet of Des Moines was passed through. The water began to flow at 1,400 feet and continued to flow at a decreasing rate for several years, until it finally stopped.

A study of section 1 in connection with the map of the State showing the locations of the artesian wells (Pl. I) shows that conditions favorable for flowing wells are found along the eastern slope of the trough extending southwestward from Iowa, as previously mentioned, at points where the elevation of the surface is not greater than 725 feet. As the surface of the country rises to the northwest, this northeast-southwest belt has a somewhat limited extent. Nearly all wells in this belt that penetrate to the base of the Des Moines—i. e., through the sandstone at the base of the Cherokee shale—have an abundant supply of water under sufficient pressure to force it to the surface. The water from this horizon is rather saline, running from 300 to 500 grains of salt to the United States gallon. Mr. Hawkins states that this saline water is used extensively by stock raisers, who believe it to be well adapted to their needs.

Water from the sandstone beds in the Missouri group, as well as from other porous beds in the Des Moines, is much more saline, and in many cases contains iron and other salts. It is probable that wells extended down to the St. Peter sandstone in this artesian belt would yield much purer water.

SECTION FROM KANSAS CITY TO LEBANON.

Section 2 (Pl. IV) shows the continuation of the trough appearing in section 1 and the western slopes of the Ozarks.

Broadhead[a] describes a diamond-drill well at Kansas City, which was sunk to a depth of 758 feet in the bottoms not far from the union railway station. The following summary is taken from the log of that well:

Summary of log of well at Kansas City.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	37	37
Des Moines	708	745
Mississippian	13+	758

Section 2 shows the northeast-southwest trend of the Iowa syncline described under section 1. It also shows the axis of the syncline to be some distance to the west, in Kansas. Winslow[b] describes a deep-well section at Raytown, Jackson County, southeast of Kansas City.

[a] Broadhead, G. C., Preliminary report on iron ores and coal fields . . . 1872, pt. 2, Missouri Geol. Survey, 1873, p. 86.

[b] Winslow, Arthur, Geologic history of Missouri: Am. Geologist, vol. 15, 1895, p. 85.

He says: "Here the base of the Paleozoic rocks was reached at a depth of 2,430 feet, and below this 36 feet of crystalline rocks were penetrated. A specimen of this core, examined by the writer, is a highly micaceous schist composed almost entirely of black mica. It is different from any rocks found in the Archean of the Southwest, and is more like rock elsewhere referred to the Algonkian." It is greatly to be regretted that Doctor Winslow did not give the full record of this well, as it is now unobtainable.

A deep drill hole at Pleasant Hill shows the top of the Mississippian at 530 feet. These rocks outcrop near the western edge of Benton County. At Decaturville, about 14 miles north of a point near Eldredge on section 2, pegmatite granite outcrops, and a study of the strata in that district shows that it is quite probable that the crystalline rocks reach an altitude of about 750 feet above sea level. A portion of the Decaturville quaquaversal is well shown in section 2, for at the deep well at Lebanon the following section is obtained:

Summary of log of well at Lebanon.

	Thickness.	Depth.
	Feet.	*Feet.*
Jefferson City limestone	427	427
Roubidoux sandstone and Gasconade limestone	580	1,007

SECTION FROM ST. JOSEPH TO VERSAILLES.

The Mississippian was reached in a well near St. Joseph at a depth of 1,250 feet. The same rocks were struck at Orric at a depth of 545 feet. At Higginsville the following general section has been obtained from the deep well of the Higginsville Prospecting Company:

Summary of log of well at Higginsville.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	68	68
Des Moines	302	370
Keokuk	87	457
Burlington	63	520
Kinderhook	195	715
Devonian (?)	55	770
Cambro-Ordovician	743	1,513

The following section was obtained from the waterworks well about 3 miles south of Sedalia and about 100 feet lower than the city:

Summary of log of waterworks well near Sedalia.

	Thickness.	Depth.
	Feet.	*Feet.*
Bottom of Mississippian		226
Devonian (?)	23	249
Cambro-Ordovician	1,151	1,400

In section 3 (Pl. IV) the waterworks-well section is combined with that of a deep well about a mile to the northwest in which, according to the statement of the driller, white sandstone was struck at a depth of 1,000 feet and continued to the bottom of the well, a distance of 1,612 feet.

The various horizons down to the Jefferson City limestone outcrop successively toward the town of Versailles, which stands near the crest of an anticlinal fold, the strata having an eastward dip to the east of the town.

Section 3 crosses over the synclinal trough outlined in the sections 1 and 2. It also illustrates artesian conditions along the western slope of the Ozark Island.

SECTION FROM FOREST CITY TO ST. LOUIS.

At Forest City, Holt County, a diamond-drill hole was sunk to the depth of 2,400 feet, and the writer is indebted to Dr. E. R. Buckley for the carefully prepared record which he made from the core. The complete log of this well, together with those of other wells mentioned in the description of the cross sections, is given in another part of this report. The summary is as follows:

Summary of log of well at Forest City.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	64	64
Missouri	866	930
Des Moines	690	1,620
Mississippian	293	1,913
Devonian (?)	128	2,041
Silurian	359+	2,400+

In an oil prospect hole on the farm of Robert Davis, 3 miles northwest of Braymer, Caldwell County, the Mississippian is reported to have been struck at 650 feet and the St. Peter sandstone at 1,250 feet. A complete record was not preserved.

At Brunswick, Chariton County, the Mississippian was reached at 180 feet. This shows the steady dip of the Pennsylvanian over the Mississippian floor to the northwest. From this point to Mexico the crest of the Ozark Island is nearly level. At Higbee the Mississippian is reached at a depth of 240 feet. At Mexico the following section is obtained:

Summary of log of well at Mexico.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	15	15
Des Moines	145	160
Mississippian	405	565
Devonian	65	630
Ordovician and Cambro-Ordovician	395	1,025

The St. Peter sandstone, 10 feet thick, was struck at 670 feet. The Des Moines comes to the surface a few miles east of Wellsville.

In Warren County the St. Peter sandstone is reached at a depth of 390 feet. Thence it dips strongly along the east edge of Ozarkia and is struck at a depth of 1,580 feet in the insane asylum well at St. Louis, where it reaches a thickness of about 133 feet. At the Belcher well in St. Louis it is reached at a depth of 1,500 feet and is 135 feet thick. In St. Louis County is a small patch of Pennsylvanian, which is 80 feet thick in the insane asylum well, and is not found in the Belcher well.

Section 4 (Pl. IV) shows the synclinal trough of the Pennsylvanian in the northwestern part of the State, the approximate contour of Ozarkia, and the St. Louis basin.

SECTION FROM ARCADIA, KANS., TO MEMPHIS, TENN.

Section 5 (Pl. IV) is made from the profile of the St. Louis and San Francisco Railroad and illustrates the dip of the Pennsylvanian to the west; one of the culminating points of the Ozarks, at Cedar Gap (the highest point reached by any railroad in the State); a general outline and cross section of Ozarkia in the southern part of the State; and the old Mississippi estuary from Black Rock, Ark., through to Memphis. Section 5 also shows Crowleys Ridge, the marked topographic prominence which is a most striking feature of the broad alluvial plain of the Mississippi and which extends from eastern Arkansas through a point south of Cape Girardeau in Missouri. This ridge is an erosion remnant of the vast Quaternary deposits that have been removed from this region, the Mississippi having flowed through the basin to the west previous to its capture by the Ohio, as already described (p. 10). The ridge is over 100 feet high throughout most of its length and of varying width.

Various mine sections and prospect drill holes in Barton County show a varying thickness of the Pennsylvanian averaging about 200 feet, the westerly dip bringing the Mississippian to the surface a little west of Golden City. At Ash Grove the Devonian is reached at a depth of 250 feet, and a sandstone, believed to be the St. Peter sandstone, at a depth of 275 feet. At Springfield several wells, drilled within a few hundred feet of each other, show the supposed St. Peter sandstone at an average depth of 320 feet. At Cedar Gap this sandstone is only slightly exposed in the sides of the ravines, and the country is capped by thin patches of the Mississippian. At Thayer the lower part of the Jefferson City limestone is well developed. The dip from Cedar Gap is generally to the southeast, and in the vicinity of Black Rock, Ark., the upper part of the Jefferson City limestone is the surface rock except at the tops of some of the highest hills, which are

capped with St. Peter sandstone. Mr. William B. Johnson gives the following section at Marked Tree, Ark.:

Section at Marked Tree, Ark.

	Thickness.	Depth.
	Feet.	*Feet.*
Lafayette sand	220	220
Lagrange formation	178+	398+

SECTION FROM DONIPHAN, MO., TO HICKMAN, KY.

Doniphan is underlain by the Jefferson City limestone. The record of a deep well which was sunk there a few years ago has, unfortunately, been lost. The Jefferson City limestone extends about 18 miles eastward to the Mississippi embayment. Crowleys Ridge is crossed by section 6 (Pl. IV) at a point where its elevation reaches about 300 feet. At New Madrid a well 295 feet deep goes for some distance into the Lagrange formation.

Prof. L. C. Glenn, of Nashville, Tenn., has kindly furnished the log of the Hickman well, with the following correlations:

Summary of log of well at Hickman, Ky.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess	80+	80
Lafayette	10	90
Lagrange	740+	830+

Section 6 gives, approximately, the Mississippi embayment and a cross section of Crowleys Ridge at one of its highest points.

SECTION FROM DONIPHAN, MO., TO CAIRO, ILL.

The Jefferson City limestone extends from Doniphan to Poplar Bluff, where the old Mississippi embayment begins. Section 7 (Pl. V) illustrates the shallower northern contour of the Mississippi embayment. The following section and correlation at Morehouse are given by Professor Glenn:

Summary of log of well at Morehouse.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay (probably alluvial)	30	30
Coarse sand (?)	110	140
Gravel	10	150
Lagrange	98	248
Porters Creek (Tertiary)	218	466
Ripley (Cretaceous)	224	690
Mississippian limestone (?)	90	780

At Cairo, Ill., the correlation of a record furnished by Mr. Ot Kochtitzky, of Cape Girardeau, furnished the following summary:

Summary of log of well at Cairo, Ill.

	Thickness.	Depth
	Feet.	*Feet.*
Loess	50	
Lafayette (?)	30	
Lagrange	237	
Porters Creek (Tertiary)	187	
Ripley sands (Cretaceous)	45	
Mississippian limestone (?)	276	

SECTION FROM PLEASANT HILL TO LOUISIANA.

Section 8 (Pl. V) is drawn not only to illustrate the western di of the Pennsylvanian toward the St. Joseph syncline, but also it irregularity of the northwestern border of Ozarkia; the developme of the northeastern anticline which has turned the course of Missou River in Saline County to the north; the synclinal basin in Sali and Howard counties, which is shown on page 81 to be the prob ble cause of the saline waters of that district; and the eastern slop of the Ozark Island, which forms a part of the synclinal valley the Mississippi at Louisiana.

Between Fayette and Louisiana no well records could be obtaine and except in regard to the outcrop of the different formations tion 8 is somewhat theoretical.

At Pleasant Hill, as already stated, a drill well struck the Mis sippian at 530 feet.

The record of the fair grounds artesian well at Sweet Sp 1,074 feet deep, furnishes the following summary:

Summary of log of well at Sweet Springs fair grounds.

	F
Pleistocene	
Mississippian	
Devonian and Cambro-Ordovician	

The St. Peter sandstone was reached at a depth of 549 fe had a thickness of 67 feet. It outcrops near Missouri River cuts across the anticline after having been deflected some to the north.

The old deep well at Boonslick, near Boonesboro, Howard County, has the following section:*

Summary of log of well at Boonslick.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	22	22
Des Moines	68	90
Mississippian	216	306
Devonian and Cambro-Ordovician	696	1,002

The St. Peter sandstone was probably reached at 607 feet and had a thickness of 101 feet.

At Fayette, Howard County, the artesian well shows 135 feet of Pleistocene and 599 feet of Des Moines and passes 271 feet into the Mississippian. Section 8 shows a very strong dip of the Mississippian rocks to the east, with a steady rise north of Fayette, where they reach the surface near North Fork of Salt River, on the line of this section. This interesting basin is referred to further in the discussion of the salt waters of Saline and Howard counties (pp. 81–82).

At Louisiana, Pike County, the Thespian artesian well, 1,350 feet deep, strikes the St. Peter sandstone at 600 feet.

SECTION FROM HIGGINSVILLE TO HANNIBAL.

Section 9 (Pl. V) is given tentatively, being one of the most difficult to correlate, and only a possible development of the horizons is outlined. The section runs through Higginsville, Malta Bend, Moberly, Rensselaer, and Hannibal. It shows the general dip of the strata to the west from Moberly to Rensselaer and a sharp anticlinal axis of Cambrian rocks at Rensselaer. Considerable disturbance and some faulting have also been noted at this point. These can not be indicated in the section. The abrupt eastern slope of the Mississippi syncline is shown between Rensselaer and Hannibal, and on each side of Rensselaer the Devonian and Ordovician rocks are indicated. The Devonian probably extends entirely through the section. The Ordovician rocks thin out between Moberly and Malta Bend, apparently not being represented in the Malta Bend record.

* The writer is indebted to Prof. J. W. Kilpatrick, of Fayette, and Prof. A. F. Hendrix, of Lawrence, Kans., for this section and for the Fayette section on p. 83.

The log of the deep well of the Higginsville Prospecting Company, furnished by Mr. J. H. Burgan, of Higginsville, gives the following summary:

Summary of log of well at Higginsville.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	68	68
Des Moines	302	370
Mississippian	345	715
Devonian	55	770
Ordovician and Cambro-Ordovician	743	1,513

The St. Peter sandstone, 150 feet thick, was struck at the depth of 1,071 feet.

The deep artesian well at Malta Bend gives the following partial summary:

Summary of log of well at Malta Bend.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	119	119
Des Moines (record incomplete)	230±	349±
Mississippian (record incomplete)	300±	649±
Devonian (record incomplete)	200±	849±

The St. Peter sandstone was struck at 900 feet and was 30 feet thick.

A portion of this record was given from memory by some of the drillers and is, probably, only approximately correct. The well is 1,300 feet deep. It has been impossible to obtain the complete record.

SECTION FROM MOBERLY SOUTHWEST TO NEVADA, THENCE SOUTH TO CARTHAGE AND EAST TO SPRINGFIELD.

Section 10 (Pl. V) shows the synclinal basin in Howard County, crossing over a portion of Ozarkia from Boonesboro to Clinton, showing the coal basins at Rockville, just south of Nevada, and again touching Ozarkia at Carthage and Springfield. It is also given for the purpose of showing the continuation of the St. Peter sandstone from Hannibal and Louisiana, on the Mississippi, westward to Fayette and around the Ozark Island on the west and south of this section to Springfield. It further demonstrates the thinning out of the Ordovician all around the Ozarks. The Ordovician rocks seem to be well developed at Macon, Moberly, and Higginsville, in an outer ring around Ozarkia; but on the slopes of the uplift they thin and abruptly disappear. This is well shown in sections 9 and 10. The Ordovician system seems also to be well developed along the west side of the

Ozark Island and northward into Iowa. It evidently once formed a penumbral margin around this elevation.

The record of the well at Moberly, 1,170 feet deep, submitted through the courtesy of Mr. W. H. Jones, of that city, gives the following summary:

Summary of log of well at Moberly.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	38	38
Des Moines	89	127
Mississippian	390	517
Devonian	68	585
Silurian (Niagara)	95	680
Ordovician	365	1,045
Cambro-Ordovician	655	1,700

The correlations in this record are based on McGee's summary of the formations found in the deep well at Macon, Macon County, a few miles north of Moberly.[a]

The same basin structure is shown in section 10 as was shown in section 8—a fact that is discussed further in the study of the saline waters of Howard and Saline counties (pp. 81–82).

The Fayette and Boonesboro wells have already been described (p. 37).

The well section at Sedalia is made by combining the records of two wells situated about a mile apart:

Summary of logs of wells at Sedalia.

	Thickness.	Depth.
	Feet.	*Feet.*
Mississippian	226	226
Devonian	23	249
Cambro-Ordovician	± 1,151	± 1,400
Cambrian or Archean	± 212	± 1,612

The St. Peter sandstone is found at a depth of 289 feet, and is 40 feet thick.

From Sedalia to Clinton the horizons are fairly uniform. At Clinton the following section was procured through the courtesy of Dr. J. H. Britts:

Summary of log of well at Clinton.

	Thickness.	Depth.
	Feet.	*Feet.*
Des Moines	40	40
Mississippian	± 150	± 190
Devonian	± 40	± 230
Cambro-Ordovician	± 570	± 800

[a] McGee, W J, Geology of Macon County: Trans. St. Louis Acad. Sci., vol. 5, No. 1, 1888, p. 327.

The St. Peter sandstone is 20 feet thick and was encountered at a depth of 290 feet.

From Clinton to Nevada, as indicated by the very imperfect record of a deep well at Rockville, there is a sag in the strata and a thickening up of the St. Peter sandstone.

The record of the Nevada deep well is very incomplete and difficult to correlate. A thickness of 170 feet of Des Moines is noted, and the St. Peter sandstone, 93 feet thick, is reached at a depth of 775 feet. About 9 miles south of Nevada an oil prospect well was put down to a depth of 1,447 feet. The imperfectly kept record of this well shows the existence of another slight synclinal trough, and a thickening up of the Des Moines to 294 feet. The St. Peter sandstone was reached at 907 feet, with a probable thickness of 100 feet. From this point southward, the Des Moines rapidly rises, the base reaching the surface beyond Lamar.

Winslow[a] gives an approximate section of a drill hole 2,005 feet deep at Carthage. It is unfortunate that his description is so incomplete as to render it impossible to correlate the section. The summary would be about as follows:

Probable summary of log of drill hole at Carthage.

	Thickness.	Depth.
	Feet.	*Feet.*
Mississippian	400	4[illegible]
Devonian	50	4[illegible]
Cambrian and Cambro-Ordovician	1,300	1,7[illegible]
Archean (porphyry)	255	2,0[illegible]

The St. Peter sandstone was reached at a depth of 560 feet, and was about 85 feet thick.

The traveler going northward from Carthage to Springfield passes up the slope of the Ozarks. Several imperfect well records show a steady dip upward on this slope. At Springfield the combined records of several adjacent wells give the following general summary:

Summary of logs of wells at Springfield.

	Thickness.	Depth.
	Feet.	*Feet.*
Mississippian	300	3[illegible]
Devonian	40	3[illegible]
Cambro-Ordovician	660	1,0[illegible]

The supposed St. Peter sandstone was reached at a depth of 350 feet, and has a thickness of 16 feet.

[a] Winslow, Arthur, Lead and zinc deposits, pt. 2: Missouri Geol. Survey, vol. 7, 1894, p. 405.

SECTION FROM PACIFIC, MO., TO GREENVILLE, ILL.

The log of the insane asylum well at St. Louis, one of the best records to be found in the State, gives the following summary:[a]

Summary of log of well at insane asylum, St. Louis.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	40	40
Des Moines	80	120
Mississippian	763	883
Ordovician	421	1,304
Cambrian and Cambro-Ordovician	2,254	3,558
Archean	285	3,843

The St. Peter sandstone was struck at 1,452 feet, and was 133 feet thick.

Section 11 (Pl. V) follows, from Pacific, the line of the Missouri Pacific Railway to St. Louis. At Pacific the St. Peter sandstone outcrops in the bluff, thus having the great dip of 1,452 feet in about 30 miles.

The different formations above this sandstone outcrop, successively, between Pacific and St. Louis, and are very well correlated in the Belcher well, situated on the bank of Mississippi River in the city of St. Louis, about 6 miles east of the insane asylum well.

Across the river, toward Caseyville and as far as Greenville, Ill., on an easterly line, the Mississippian and Pennsylvanian successively outcrop under the loess, dipping gently to the east. The structural conditions of the beds between Mississippi River at St. Louis and Caseyville, Ill., are only conjectural. There may be a low anticline, or there may be faults. The Mound City well section would indicate a gentle dip to the east as more probable. As no well sections from this area are available, the existence of a low anticline can only be assumed.

At Godfrey, Ill., a few miles to the northeast of section 11, a well was sunk to a depth of 1,703 feet, in which St. Peter sandstone was struck at 1,625 feet. The writer is indebted for this section to Mr. D. W. Maxfield, of Monticello Seminary.

SECTION FROM KEOKUK, IOWA, TO ST. LOUIS, MO.

A summary of the formations in the well of the Keokuk Poultry Company, at Keokuk, Iowa, is taken from Norton's Artesian Wells of Iowa.[b]

[a] Broadhead, G. C., Trans. St. Louis Acad. Sci., vol. 3, No. 2, 1878, p. 219.
[b] Iowa Geol. Survey, vol. 6, 1897, p. 235.

Summary of log of well at Keokuk, Iowa.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	5	5
Keokuk	130	135
Montrose cherts (Mississippian)	30	165
Burlington, upper part of (Mississippian)	22	187
Burlington, lower part of (Mississippian)	103	290
Kinderhook (Mississippian)	206	496
Devonian	85	581
Silurian	120	701

The St. Peter sandstone, 110 feet thick, was struck at a depth of 1,050 feet in the Hubinger well, not far from the well of the Keokuk Poultry Company. Norton estimates that this sandstone would be struck in the latter well at 1,250 feet.

At Canton, Lewis County, an artesian well was sunk in 1890 to a depth of 906 feet. The St. Peter sandstone was struck at 846 feet, and drilling was stopped in this rock at 906 feet, showing a thickness of 60+ feet.

At Lagrange, in the same county, two artesian wells were sunk. The Thomas well on the bluff at an altitude of 580 feet struck St. Peter sandstone at 800 feet, and the Wyaconda at an altitude of 481 feet struck this rock at 700 feet, passing into it for 115 feet.

The well of Dr. A. Vernet, near Hannibal, Marion County, was sunk to a depth of 1,340 feet. The record was furnished the writer by Mr. R. Hawkins, of Chillicothe, and from it the following summary was made:

Summary of log of Vernet well, near Hannibal.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene	41	41
Mississippian	259	300
Devonian (?), Silurian, and Ordovician to St. Peter sandstone	301	601
St. Peter sandstone	96	697
Jefferson City limestone	253	950
Roubidoux sandstone	390	1,340

At Louisiana, Pike County, the Thespian artesian well has a depth of 1,350 feet. Unfortunately the record of this well has been lost, but it is known that the St. Peter sandstone was struck at a depth of 600 feet.

From Louisiana southward to St. Louis the country is very much broken and disturbed. The Cap au Grès fault crosses the river near Winfield. As there are no well sections between Hannibal and St. Louis only a theoretical outline of the geology can be shown in section 12 (Pl. V). The St. Peter sandstone comes to the surface in Lincoln County and then dips sharply to the south, being found in the insane asylum well, as described on page 41, at a depth of 1,452 feet.

East of Hannibal, at Barry, Ill., in a well 2,500 feet deep,[a] the St. Peter sandstone was struck at 1,125 feet. The altitude of Barry is 617 feet and that of Hannibal 472 feet. The sandstone was struck at Hannibal at 601 feet.

UNDERGROUND WATERS.

ARTESIAN DISTRICTS.

The State may be conveniently and somewhat arbitrarily divided into the following ten districts: (1) The northeastern, (2) the north central, (3) the south central, (4) the Decaturville dome, (5) the Clinton-Nevada, (6) the southeastern, (7) the St. Louis basin, (8) the St. Francis Mountains, (9) the southeastern swamp, (10) the drift.

NORTHEASTERN DISTRICT.

GENERAL ARTESIAN CONDITIONS.

The northeastern district includes the portions of the counties north of St. Charles County that lie between Mississippi River and the ridge a few miles to the west. The artesian wells obtain their flow from the eastern slope of the northern extension of the Ozark uplift. In the northeast corner of the State for some miles back from the river the Des Moines group forms the country rock. Along the Mississippi from the Iowa border nearly to Louisiana, Mo., and for some distance inland farther south, Missouri rocks outcrop. In the vicinity of Louisiana a narrow belt of Silurian appears. The dip is strongly to the east. The St. Peter sandstone rises steadily from Iowa toward the south. In this district the drillers' records are meager and poorly kept. There are flowing wells at or near Canton and Lagrange, Lewis County; Hannibal, Nelsonville, and Oakwood, Marion County; Spalding, Ralls County; Louisiana, Pike County; and Troy, Lincoln County.

Flowing artesian water in this district may be found in a narrow belt extending from Keokuk probably to a point a little south of Louisiana. The belt is limited because of the more or less abrupt slope toward the river and the relative nearness of the crest of the divide to the river valley, as shown in sections 8 and 9 (pp. 36–37). The water is derived mainly from the St. Peter sandstone, which, so far as can be learned, is the highest horizon yielding flowing water. As a rule potable nonflowing water may be found at the base of the Mississippian. It is not probable that water will rise to an altitude of much over 600 feet in this district, and owing to the high elevation of the towns along the divide it is questionable whether that will be within proper pumping distance.

[a] Leverett, Frank, Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 810.

It is rather interesting to notice the general increase in mineral constituents in the water southward from the Iowa line, as shown by the following table:

Statistics of wells in northeastern district.

Well.	Depth (feet).	Temperature (° F.).	Total solids (parts per million).	Sodium chloride (parts per million).
Canton	906	60	385.76	266.249
Wyaconda	850	60	373.266	286.834
Lagrange	800	61	395.571	320.607
Spalding	300	57	700.3112	533.261
Louisiana	1,350	63.5	552.2904	410.721

An increase in the amount of the other mineral constituents as well as of salt is noticed in these wells. Samples of St. Peter sandstone, procured from several shallow wells in Ralls County, show the presence of minute disseminated grains of marcasite (iron pyrites) which will perhaps account for the increasing amount of sulphureted hydrogen. The catchment basin for the St. Peter sandstone is probably in Wisconsin, the water flowing through Iowa and meeting with a gentle upward dip, as noted in the sections, so that when it reaches Missouri it undoubtedly has its mineral constituents concentrated, as is indicated by the foregoing table.

CLARK COUNTY.

KAHOKA.

The following is the log of one of three deep nonflowing wells at the pickle plant of the Clark County Canning Company, Kahoka:

Log of Clark County Canning Company well, Kahoka.

	Thickness.	Depth.
Pleistocene (157 feet):	*Feet.*	*Feet.*
Gumbo	20	20
Yellow clay	20	40
Sand	10	50
Blue clay	20	70
Gray clay	30	100
Yellow clay	40	140
Blue clay	10	150
Sand	7	157
Keokuk (131 feet):		
Rock, shelly	2	159
Solid rock	31	190
Limestone	10	200
Gray limestone	10	210
"Soapstone"	13	223
Water-bearing rock	11	234
Shale	6	240
Sandstone	16	256
Shale	2	258
Rock	12	270
Soft rock	18	288
Burlington (72 feet):		
Limestone	22	310
Shale	5	315
Limestone	45	360

The first water was struck at a depth of 60 feet, and a still larger body was encountered in the honeycombed limestone at a depth of 198 feet. The well was shot with dynamite at different depths, after which it was cleaned out. Excellent water stands at 72 feet below the surface.

The Kahoka city water supply is obtained from a well 509 feet deep. Drilling was started in December, 1901, by George C. Morgan, of Chicago, and the well was finished in March, 1902. The water, which is wholesome, abundant, rather hard, and usually clear, rises within 90 feet of the surface or to the top of the rock, as the Pleistocene is 90 feet thick. A reservoir with a capacity of 75,000 gallons provides water, with direct pressure, for city consumption. No log of this well has been preserved, and no analysis has been made. The cost of the well and pump was $3,000 and the supply of water is ample for the needs of a city of 2,500 people.

LEWIS COUNTY.

CANTON.

At Canton a well is situated on the grounds of the Christian University, about 1 mile west of the river, at the summit of a picturesque bluff. Its elevation is about 600 feet; depth, 900 feet; 6-inch casing to 100 feet; temperature of water, 60°; of air, 80°; flow, 72 gallons per minute; pressure, 12 pounds; date of completion, 1890; cost, $1,812. The first water was struck at a depth of 90 feet, and rose within about 10 feet of the top. At a depth of 870 feet, in the St. Peter sandstone, a strong flow of water was struck, which had a gaged pressure of 12 pounds. Mr. L. H. Condit, the postmaster at Canton, superintended the drilling. He states that when the drill struck the sandstone, which was spongy and water-logged, it went down several feet. No record of the well was kept. Although this well is located on the grounds of the Christian University, it was drilled at the expense of the city under a lease for forty-nine years, and Messrs. Griffith and Maggard, of the Aqua Vitæ Mineral Springs Company, have sub-leased the right to ship the water for medicinal purposes. The water possesses mildly laxative qualities. The well was originally put down by the city for fire protection, and its saline properties made it of especial value for this purpose, as fire once under control by this water has little chance of reignition. Insurance companies have recognized this fact and have cut their rates about one-half for this town.

The water is used for all domestic purposes, except that of watering lawns, and there are about 9 miles of mains. It is clear and sparkling, with a slight sulphur odor, and is strongly charged with sulphureted hydrogen. This well is interesting from the fact that its

flow has steadily increased. When first tested it flowed 53 gallons per minute. In 1903 it was opened and water and gas issued with great force, due to the accumulation of gas. It was again tested and found to flow 72 gallons per minute.

An analysis of this water, made by Prof. Harrison Hale, of Drury College, resulted as follows:

Analysis of water from Canton, Lewis County.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	5.3	Carbonate radicle (CO_3)	[illegible]
Iron (Fe)	Trace.	Bicarbonate radicle (HCO_3)	[illegible]
Calcium (Ca)	252.0	Sulphate radicle (SO_4)	[illegible]
Magnesium (Mg)	142	Chlorine (Cl)	[illegible]
Sodium (Na)	1,858		
Potassium (K)	86		[illegible]

It will be noticed that this water somewhat resembles the sulphosaline water of Excelsior Springs. It is gaining a considerable reputation.

LAGRANGE.

Close to the west side of the Burlington Railway track, at Lagrange, a short distance from the railway station, is a well owned by the Lagrange Mineral Well Prospecting Company. The depth is 800 feet; elevation above tide at well mouth, 481 feet; casing, 6-inch, 850 feet; temperature of water, 61° F.; of air, 86° F.; flow, 60 gallons per minute; date of completion, 1887; cost, $1,500; surface formation, Keokuk limestone.

This well is 2,500 feet deep and was sunk with the expectation of finding some profitable mineral. The first water was reached at 400 feet. At 800 feet a strong flow was struck, and at 850 feet it became so strong that the driller could go no farther. This flow comes from the soft, water-logged St. Peter sandstone, and no perceptible change has ever been noticed in either its volume or force. Mr. R. N. Blackwood states that the force was sufficient to carry the water to the summit of the bluff, a distance of over 100 feet. This well has recently been sold to Mr. Thomas, the owner of the Wyaconda well, and the product of both wells is shipped under the name of Wyaconda water.

The Wyaconda well is on the summit of a bluff overlooking the town of Lagrange, about 1 mile north and about 100 feet above the well just described. The owner is William H. Thomas; depth, 850 feet; diameter, 8 inches; altitude at well mouth, 580 feet above tide; casing, 5½-inch, 150 feet; temperature of water, 60° F.; of air, 80° F.; flow, 40 gallons per minute; date of completion, January, 1888; cost, $1,500; surface formation, Keokuk limestone.

[a] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

The main flow of water was reached at 800 feet, in the soft, white St. Peter sandstone; it is steadily decreasing in volume. In both this and the Lagrange well the flow increased when the St. Peter sandstone was reached. The following is the incomplete log of the well:

Log of Wyaconda well, Lagrange, Lewis County.[a]

	Thickness.	Depth.
Pleistocene (15 feet):	*Feet.*	*Feet.*
Soil	15	15
Mississippian (480 feet):		
Limestone	200	215
Shale	65	280
Soft limestone	65	345
Soft shale, slate, or soapstone	150	495
Devonian (?) (150 feet):		
Dry "Trenton" (?) rock	150	645
Silurian and Cambrian, including St. Peter sandstone (205 feet):		
Limestone	155	800
White sandstone	50	850

[a] The writer is indebted to Mr. William H. Thomas for the logs of the Wyaconda and Lagrange wells.

Two analyses of this water have been made, one of which, by Prof. Paul Schweitzer, is as follows:

Analysis of Wyaconda mineral water.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	40	Bicarbonate radicle (HCO_3)	2.9
Iron (Fe)	1.3	Sulphate radicle (SO_4)	1,055
Calcium (Ca)	293	Chlorine (Cl)	2,975
Magnesium (Mg)	89		6,392.2
Sodium (Na)	1,934		
Potassium (K)	Trace.	Free CO_2	260
Lithium (Li)	Trace.		

But an imperfect record of the drillings was kept, and only the following data can be given:

Partial log of Wyaconda well, Lagrange, Lewis County.

	Thickness.	Depth.
Pleistocene (15 feet):	*Feet.*	*Feet.*
Soil	15	15
Mississippian (360 feet):		
Limestone	80	95
Shale	70	165
Soft limestone	55	220
Soft slate, shale, or soapstone	155	375
Devonian (110 feet):		
Dry limestone	110	485
Silurian and Cambrian, including St. Peter sandstone (315 feet):		
Trenton rock (?)	200	685
Very soft white sandstone	115	800

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

With this meager record it is difficult to correlate the various formations passed through, but a comparison with the well at Keokuk makes the above determinations probable.

An analysis of this water, made by C. A. Crampton, Washington, D. C., shows the following results:

Analysis of water of Wyaconda well, Lagrange, Lewis County.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	49	Carbonate radicle (CO_3)	664
Iron (Fe)	Trace.	Sulphate radicle (SO_4)	107
Aluminum (Al)	.8	Chlorine (Cl)	3,326
Calcium (Ca)	246		4,767.8
Magnesium (Mg)	101		
Sodium (Na)	2,214	Free CO_2	288
Potassium (K)	60		

LINCOLN COUNTY.

TROY.

Near Troy, Lincoln County, is a well owned by N. Hanni, of which the depth is 136 feet; altitude, 15 feet above the railway station; casing, 6-inch, 10 feet to rock; flow, a small stream, about 1 gallon per minute; date of completion, 1893; surface formation, Burlington limestone. In this well flowing water was struck in an open crevice between 125 and 130 feet. The supply decreases with pumping, and consequently the well flows only after the pumps have been stopped for some time. No log was kept; but it is stated that chert and an easily drilled, fine-grained white limestone were passed through. It is probable that drilling was stopped in the lower part of the Burlington. Another well in Troy, 100 feet deeper, does not flow.

The following analysis of the water of the Hanni well was furnished by Mr. E. E. Ellis:

Analysis of water of Hanni well, Troy, Lincoln County.

	Parts per million.		Parts per million.
Iron	0	Total carbonates	[illegible]
Sulphates	29	Alkaline carbonates	[illegible]
Chlorine	7.47	Alkaline and earthy carbonates	[illegible]
Total hardness	208.5	Calcium	[illegible]

MARION COUNTY.

HANNIBAL.

On the west edge of the city of Hannibal, about 1¼ miles west of the railroad station, is a well owned by Mrs. Vernet. The depth is 1[illegible] feet; altitude, 608 feet, or 135 feet above the union railroad station.

[a] Expressed by analyst in grains per gallon and hypothetical combinations. Recomputed to [illegible] form and parts per million at United States Geological Survey.

Hannibal; diameter of casing, 6 inches; temperature, 57.2° F.; water stands within 12 feet of top of well; date of completion, 1894; surface formation, lower part of the Burlington. The writer is indebted to Mr. R. Hawkins, of Chillicothe, for the following record of this well:

Log of Vernet well, Hannibal, Marion County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (41 feet):		
Soil and clay	41	41
Mississippian (259 feet):		
Shales, limestone, and hard water	154	195
Blue limestone	105	300
Devonian (?), Silurian, and Cambrian to St. Peter sandstone (301 feet):		
Black slate	33	333
Salt-water sand; water rose within 70 feet of surface	14	347
Solid limestone	254	601
St. Peter sandstone (96 feet):		
Mineral-water sand; water rose within 30 or 40 feet of surface	96	697
Jefferson City limestone (253 feet):		
Limestone and hard, fine sand at intervals; water rose within 20 feet of surface	253	950
Roubidoux sandstone (439 feet):		
Hard limestone	50	1,000
Soft white sand; water rose within 7 feet of surface	5	1,005
Limestone	50	1,055
Limestone with interstratified sand	150	1,205
Sand	20	1,225
Magnesian limestone	50	1,275
Hard white sand; water stands within 4 feet of surface	10	1,285
Magnesian limestone; water flowing	104	1,389
Unaccounted for	46	1,435

This well was put down by Dr. Fred. Vernet for the purpose of obtaining mineral water. The water is very saline, being similar to that of the Stilwell well in Hannibal. The following analysis is taken from an advertising circular published by Doctor Vernet; the analyst and date of analysis are unknown:

Analysis of water of Vernet well, Hannibal, Marion County.[a]

	Parts per million.		Parts per million.
Iron (Fe)	41	Carbonate radicle	422
Calcium (Ca)	49	Sulphate radicle (SO_4)	790
Magnesium (Mg)	108	Chlorine (Cl)	58
Sodium (Na)	363		
Lithium (Li)	26		1,857

In 1889 J. M. Tracy drilled a well for oil on the same tract of land as that on which the Vernet well is situated. The elevation was 50 feet above the railroad station at Hannibal and 85 feet below Doctor Vernet's well. Fresh water was found at the bottom and rose within a few feet of the surface.

In an alley near Front street, corner of Hill street, close to the steamboat wharf, is a well owned by the Richard Stilwell Meat and Ice Company. The depth is 950 feet; altitude, 475 feet; casing, 8-inch, 200 feet; temperature of water, 60° F.; of air, 88° F.; flow,

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

fairly strong, 208 gallons per minute; pressure by steam gage, 50 pounds; date of completion, 1890; surface formation, Louisiana limestone. The first water, nonflowing, was struck at 40 feet; the next stream, flowing, was encountered at 800 feet, in the soft, white St. Peter sandstone; and it is claimed that for 100 feet in this sandstone alternating streams of fresh and salt water were struck. The water is highly charged with saline ingredients, and sulphureted hydrogen bubbles up freely. The flow is estimated at 300,000 gallons in twenty-four hours. No log of this well could be obtained. The following analysis of the water was made by E. E. Ellis, May 31, 1905:

Analysis of water of Stilwell well, Hannibal.

	Parts per million.		Parts per million.
Iron	Trace.	Alkaline earthy carbonates	274.4
Calcium	150+	Sulphates	522
Alkalinity	274.4	Chlorides	Very high.
Alkaline carbonates	0		

Turbidity, none; color, none.

The water is very salty and contains a large amount of sulphureted hydrogen.

NELSONVILLE.

The following data have been collected about the wells at Nelsonville. Well No. 1 is in sec. 28, T. 59, R. 8 W.; owner and driller C. H. Mohr; first flow at about 650 feet. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of well No. 1, Nelsonville, Marion County.

	Thickness.	Depth.
Blue shale, fresh water	[illegible]	[illegible]
Hard limestone	[illegible]	[illegible]
Gray shale	[illegible]	[illegible]
Limestone, very hard	[illegible]	[illegible]
Red sandstone	[illegible]	[illegible]
Limestone	[illegible]	[illegible]
Sandstone	[illegible]	[illegible]
Limestone	[illegible]	[illegible]
Sandstone	[illegible]	[illegible]
Blue shale	[illegible]	[illegible]
Sandstone	[illegible]	[illegible]

Well No. 2 is 3 miles south of Nelsonville, in sec. 21, T. 59, R. 8; owner and driller, C. H. Mohr. The well was drilled with 4½-inch tools. It flows 10 gallons per minute, and the water rises 12 feet above the mouth. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of well No. 2, Nelsonville, Marion County.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	45	45
Blue shale	150	195
Limestone	60	255
Gray shale	35	290
Limestone	220	510
Red sand; some oil and gas	15	525
Limestone	125	650
White sandstone; mineral water	10	660
Hard rock	2	662
Sandstone	213	875

PALMYRA.

At Palmyra a well was sunk to a depth of 1,683 feet. The water is said to have flowed at 700 feet. The analysis here given was made by Prof. Paul Schweitzer in 1887.

Analysis of water of well at Palmyra, Marion County.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	19	Sulphate radicle (SO_4)	814
Calcium (Ca)	515	Chlorine (Cl)	6,443
Magnesium (Mg)	234	Bromine (Br)	4
Sodium (Na)	3,542		
Lithium (Li)	.9		11,571.9

OAKWOOD.

A deep well was sunk in 1890 at Oakwood, 3 miles southwest of Hannibal, on the land of C. G. Price, but it ceased to flow some years since. The log was lost. This well was about 800 feet deep and located 150 feet above the river. It had a very strong flow, but it was stopped up because the highly saline water injured vegetation. The following analysis of this water, furnished by Mr. Price, was made by R. Chauvenet & Brother:

Analysis of water of well at Oakwood, Marion County.[a]

	Parts per million.
Calcium (Ca)	634
Magnesium (Mg)	249
Sodium (Na)	5,233
Sulphate radicle (SO_4)	3,401
Chlorine (Cl)	7,388
	16,905

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

PIKE COUNTY.

LOUISIANA.

A well, now called the "Thespian Spring," is located in the small valley of Town Branch, corner of Fifth and Kentucky streets, in the town of Louisiana. Owner, C. W. Crudson; depth, 1,275 feet; altitude, 470 feet; date of completion, 1887; casing, 6-inch, to 910 feet; temperature of water, 63.5° F.;[a] of air, 92° F.; cost, $3,000.

The water is strongly saline and charged with sulphureted hydrogen. It is clear, sparking, and bubbling with gas, and has corroded the rock basin into which it empties. The water comes up with considerable force, having a head, probably, of about 8 feet. It is stated that when the well was first opened it threw a jet 40 feet high. The flow is said to be stronger after a wet period and weaker in dry weather. A sanitarium, with bottling facilities, has been established near the well, and the water was once bottled and shipped to St. Louis. It is now used for bathing and, to a limited extent, for drinking.

Schweitzer[b] gives the following meager log, which he obtained from William H. Suda:

Log of Thespian Spring, Louisiana, Pike County.

	Thickness.	Depth.
	Feet.	*Feet.*
Loose soil	90	90
Sandstone	560	650
Limestone	120	770
Sandstone	30	800
Undetermined	10	810
Sandstone	70	880
Undetermined	395	1,275

This record is so manifestly incorrect that no satisfactory correlations can be made. It was stated that the first flow of water was struck at 600 feet, in sandstone. Prof. R. R. Rowley gives the following geologic data: "At Louisiana the Hudson River limestone is 40 feet thick, and under that is 100 feet of Trenton limestone. The St. Peter sandstone would probably be reached at about 600 feet."

[a] This temperature was obtained July 15, 1903. Schweitzer, in his report on Mineral waters of Missouri (Missouri Geol. Survey, vol. 3, 1892), gives a temperature of 62.2° F., with air temperature 74° F., probably taken in 1892.

[b] Missouri Geol. Survey, vol. 3, 1892, p. 94.

The following analysis, date and name of chemist unknown, is given on the circular published by the owners of the well:

Analysis of water from Thespian Spring, Louisiana, Pike County. [a]

	Parts per million.		Parts per million.
Silica (SiO_2)	0.4	Chlorine (Cl)	4,774
Calcium (Ca)	410	Bromine (Br)	34
Magnesium (Mg)	200		9,459.5
Sodium (Na)	2,796	H_2S	478
Potassium (K)	17	CO_2	805
Lithium (Li)	3.1		10,742.5
Bicarbonate radicle (HCO_3)	345		
Sulphate radicle (SO_4)	879		

Schweitzer [b] gives the following analysis:

Analysis of water of Thespian Spring, Louisiana, Pike County. [a]

	Parts per million.		Parts per million.
Silica (SiO_2)	4.9	Bicarbonate radicle (HCO_3)	186
Calcium (Ca)	420	Sulphate radicle (SO_4)	1,051
Magnesium (Mg)	165	Chlorine (Cl)	4,677
Sodium (Na)	2,775		9,341.9
Potassium (K)	63		

RALLS COUNTY.

RENSSELAER.

Mr. J. M. Johnson, of Rensselaer, gives the record of a stock well 270 feet deep, situated on his farm 1½ miles from Rensselaer station in Ralls County. He also sent samples of drillings to accompany the log, which follows:

Log of Johnson well, Rensselaer, Ralls County.

	Thickness.	Depth.
	Feet.	*Feet.*
1. Pleistocene	28	28
2. Limestone and shale	172	200
3. Brown shale	60	260
4. Limestone and fresh water		
5. Soft white sandstone	10	270

Of these samples, No. 2 corresponds with Swallow's Onondaga limestone. No. 5 is, without doubt, the St. Peter sandstone; it is made up of incoherent, fine, rounded, polished, and waterworn grains of limpid quartz. Occasional specks of marcasite (iron pyrites) were found, which might possibly account for the sulphureted hydrogen and sulphates that abound in the waters of this region.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

[b] Op. cit., p. 96.

SPALDING.

About 5 miles south of Rensselaer station, on the Missouri, Kansas and Texas Railway, in sec. 25, T. 56, R. 6 W., at the post-office of Spalding, is a very interesting well, owned by R. M. Spaulding. Depth, 330 feet; altitude at well mouth, about 590 feet above tide; temperature of water, 57° F.; of air, 86° F.; flow, 400 gallons per hour; date of completion, about 1823; drillers, Hager & Muldrow; drilled by hand. This well is on an old French grant known as the Boovat Lick. Several salt springs are situated a few hundred feet to the north. Some time after 1821, probably about 1823, the State engaged Messrs. Hager & Muldrow to sink the well. Several veins of water, some soft and some salt, were struck. The first strong flow was obtained at 300 feet in soft sandstone, which was penetrated to a depth of 30 feet. Various attempts were made to case this well with wooden tubing, but the pressure was too strong, and with the exception of a wooden tube passed through the soil and firmly anchored to rock no casing was put in. The source of the water was the St. Peter sandstone. So far as observed the pressure has always remained the same. Salt was obtained from this well and the adjoining springs for many years. The water is very strongly saline and is charged with sulphureted hydrogen, so that white precipitate forms about the boards and pipes connected with the well. This place has long been a summer resort.

No record was kept of the geologic horizons passed through, but there is no doubt of the fact that the source of supply is the St. Peter sandstone. The strata in the vicinity of the well are greatly disturbed. North of the well the rocks dip 15° SW., with a strike of N. 40° W. In the farm owned by Mr. Spaulding's son, about a mile southeast of the well, the strata are much more disturbed. The St. Peter sandstone stands with upturned edges and is overlain by ledges of Joachim limestone. An anticline having a northwesterly trend passes through this portion of the country and the artesian well is situated on its southern slope. Geologically this is a region of great interest. Three miles northwest of Spalding, in the road near the Tompkins's place, the rock dips strongly to the northeast. This is probably near the axis of the anticline just mentioned.

The following analysis of this water is taken from Schweitzer's report:[a]

Analysis of water from well at Spalding, Ralls County.[b]

	Parts per million		Parts per million
Silica (SiO_2)	5.8	Bicarbonate radicle (HCO_3)	[illegible]
Calcium (Ca)	511	Sulphate radicle (SO_4)	[illegible]
Magnesium (Mg)	213	Chlorine (Cl)	[illegible]
Sodium (Na)	3,596		
Potassium (K)	78		[illegible]

[a] Missouri Geol. Survey, vol. 3, 1892, p. [illegible].

[b] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million by the United States Geological Survey.

NORTH-CENTRAL DISTRICT.

GENERAL ARTESIAN CONDITIONS.

The north-central district includes the portion of Missouri north and northwest of the Atchison, Topeka and Santa Fe Railway, which crosses the State in a northeast-southwest direction, from Des Moines River to Kansas City. The wells in this district obtain water from the Des Moines group, the basal formation of which is usually a porous sandstone. The waters have their head on the western slope of the great divide which runs in a north-south direction through the northern part of the State and which is probably the northeastern extension of the Ozark dome. The water is generally strongly saline and often chalybeate, but it is considered excellent for the use of stock, though it is not generally desirable for drinking. There is sufficient pressure to bring the water to the surface where the surface elevation does not exceed 730 feet. Very few wells have reached the St. Peter sandstone. Those that have been drilled to this formation have a surface elevation too high to admit of flow.

The general dip is to the northwest toward the St. Joseph trough, but this dip is not uniform. Near Utica, Livingston County; Jamesport, Daviess County; and Bethany, Harrison County, are anticlinal folds and faultings. The average dip is from 10 to 15 feet to the mile. The land rises regularly in this direction, so that the Des Moines group is deeply buried. The flowing wells are found in this district at or near the following places: Carrollton, Carroll County; Utica, Livingston County; Gallatin, Daviess County; Bethany, Harrison County; and in Mercer County, near Lineville, Iowa.

ADAIR COUNTY.

KIRKSVILLE.

At Kirksville is a well that was sunk for the purpose of obtaining a city supply. The writer is indebted to Hon. Thomas J. Dockery for the following log of this well:

Log of deep well at Kirksville, Adair County.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Pleistocene (170 feet):				
Clay	170	0	170	0
Des Moines (280 feet):				
Limestone	8	0	178	0
Coal		1	178	1
Clay shale	30	0	208	1
Sandstone	22	0	230	1
Shale	15	0	245	1
Hard limestone	2	0	247	1
Shale, about	20	0	267	1
Coal	1	6	268	7
Shale	30	0	298	7
Shelly broken limestone	20	0	318	7
Soft, mushy, blue clay	20	0	338	7
Limestone	15	0	353	7
Coal	2	0	355	7
Shale	50	0	405	7
Fine white sandstone	45	0	450	7
Mississippian (840+ feet):				
Solid limestone	700	0	1,150	7
Flint, very hard limestone, and sandstone	140	0	1,290	7

As Kirksville is situated on the crest of the dividing ridge between Missouri and Mississippi rivers, at an altitude of 975 feet, there was no possibility of obtaining flowing water. Water was struck at a depth of 1,150 feet and rose within 240 feet of the surface. It was highly impregnated with sulphur and iron.

CALDWELL COUNTY.

BRAYMER.

The following record of a well on the farm of Dan Braymer was furnished by Mr. R. Hawkins, of Chillicothe. The surface elevation at the well is about 765 feet.

Log of well of Dan Braymer, near Braymer, Caldwell County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (26 feet):		
Dirt	8	8
Shale	8	16
Blue shale	10	26
Des Moines (420 feet):		
Red shale	10	36
Limestone	6	42
Blue shale	8	50
Limestone	10	60
Blue shale	10	70
Flint rock	13	83
Hard white shale	10	93
Limestone	4	97
Sand rock	4	101
Hard white shale	12	113
White limestone	11	124
Blue shale	14	138
Sand rock	40	178
Limestone	6	184
Slate	6	190
Blue shale	27	217
Limestone	2	219
Slate	1	220
Coal	1	221
White shale	4	225
Limestone	4	229
Blue shale	2	231
Limestone	1	232
Slate	6	238
Blue shale	4	242
Hard white sand rock	14	256
Shale	57	313
Limestone	3	316
Red shale	2	318
Limestone	2	320
Blue shale	15	335
Sand rock	20	355
Slate	2	357
Brown sand rock	15	372
Coal	1	373
Saline water stratum	65	438
Black shale to Mississippian limestone; drilled 11 feet into this limestone	8	446

CARROLL COUNTY.

CARROLLTON.

One-half mile northeast of the city of Carrollton, on the west bank of Brush Creek, is a well owned by Hugh K. Rea.[a] Altitude, about 660 feet above tide (about 70 feet lower than the Carrollton public square); depth, 241 feet; flow, feeble; date of completion, 1890; driller, J. C. Ferrie, of the Mallory Diamond Drill Company, Chariton, Iowa; surface formation, Des Moines; cost of well, $900.

The distance to the principal source of water in the basal sandstone of the Cherokee shales is 200 feet. The last 7 feet are in the chert of the Mississippian. The flow is estimated to be about a gallon in three minutes and is uniform, having neither increased nor decreased.

Another well, similar in character, was sunk about 1,200 feet southwest of the above. The following log was preserved by Mr. Wilcockson:

Log of well at Carrollton, Carroll County.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Pleistocene (25 feet)	25	0	25	0
Des Moines (234 feet):				
Gray shale	13	0	38	0
Dark shale	11	0	49	0
Limestone	1	0	50	0
Gray shale	3	0	53	0
Limestone	1	0	54	0
Dark shale	5	0	59	0
Limestone	1	0	60	0
Dark gray shale	6	0	66	0
Sandstone	3	0	69	0
Shale, with 12 inches slaty coal	21	0	90	0
Shale	30	0	120	0
Sandstone	4	0	124	0
Shale	17	0	141	0
Sandstone	3	0	144	0
Shale	47	0	191	0
White, soft sandstone; water rose to surface	20	0	211	0
Dark shale	5	0	216	0
Red sandstone	6	0	222	0
Dark shale	10	0	232	0
Coal		5	232	5
Dark shale	1	7	234	0
Mississippian (7 feet):				
Hard chert	7	0	241	0

A flow of saline water was struck between 200 and 210 feet. The water has no odor, but the contained gas will blow a cork from a bottle of it in a few minutes. This water is used for drinking purposes and for stock. It is slightly laxative. No analysis has been made.

[a] The writer is indebted to Mr. J. M. Wilcockson, of Carrollton, for data concerning this well.

TINA.

A prospect hole for oil, drilled on the farm of C. W. Nuss, at Tina, at an elevation of about 706 feet, gave the following record, which was furnished by Mr. R. Hawkins, of Chillicothe:

Log of prospect hole at Tina, Carroll County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (40 feet):		
Clay and sand	40	40
Des Moines (345 feet):		
Flint	4	44
Coal	4	48
Shales	20	68
Limestone	5	73
Coal	2	75
Shales	215	290
Sand rock	40	330
Black slate	55	385
Mississippian (290 feet):		
Brown limestone	40	425
Flint (probably cherty limestone)	95	520
"Slate"	5	525
Gravel	2	527
Flint, "hog chawed"	40	567
"Slate" and black limestone	75	642
Gravel and sand, with water	5	647
Very hard, flinty limestone, interstratified with other beds; water from bottom slightly alkaline	28	675

CLAY COUNTY.

EXCELSIOR SPRINGS.

Near the town of Excelsior Springs, in the northeast corner of Clay County, about 30 miles northeast of Kansas City, are two deep drilled wells—the sulphosaline, 1,460 feet deep, and the salt-sulphur, 1,370 feet deep. It is unfortunate that no record of these wells has been preserved. The waters are in all probability mainly derived from the Jefferson City limestone and the base of the Pennsylvanian. The information regarding these wells was furnished by Mr. C. W. Fish, general manager of the Excelsior Springs Company.

The sulphosaline well is located about 1 mile north of the town of Excelsior Springs in a narrow valley on the west bank of Fishing River; owner, Excelsior Springs Mineral Water Company; depth, 1,460 feet; altitude above tide, about 925 feet; diameter of casing, 34 inches; temperature of water, 67° F.; of air, 84° F.; date of completion, 1888; cost, $1,200; surface formation, upper part of Des Moines. The water stands within 150 feet of the top of this well and is pumped by a Eureka pump run by a 10-horsepower engine. It is very corrosive, and ordinary pipes last only about three years; galvanized pipes last ten years. The water is clear and sparkling, with a saline taste and a slight odor of sulphur. It contains a small amount of carbon dioxide gas.

The salt-sulphur well was sunk by W. S. Pryor, of Kansas City. The water is pumped to the Music Hall bath house, which has a swimming pool 60 by 32 feet. The owners are E. L. and E. I. Morse; depth, 1,327 feet; altitude, about 925 feet; cased to bottom; date of completion, 1899; water stands within 60 feet of surface; surface formation, upper part of Des Moines.

The following analyses of water from these two wells are given in Schweitzer's report:[a]

Analysis of water from sulphosaline well, Excelsior Springs, Clay County.[b]

	Parts per million.		Parts per million.
Silica (SiO_2)	10	Bicarbonate radicle (HCO_3)	234
Iron (Fe)	.7	Sulphate radicle (SO_4)	1,126
Aluminum (Al)	21	Chlorine (Cl)	3,808
Calcium (Ca)	239		8,189
Magnesium (Mg)	98	Residue on ignition	8,093
Sodium (Na)	2,610		
Potassium (K)	42		

Analysis of water from salt-sulphur well, Excelsior Springs, Clay County.

(Analyst, E. H. S. Bailey.)

	Parts per million.		Parts per million.
Silica (SiO_2)	11	Sulphate radicle (SO_4)	396
Iron (Fe)	4.7	Chlorine (Cl)	6,684
Calcium (Ca)	210	Bromine (Br)	14
Magnesium (Mg)	109	Iodine (I)	12
Sodium (Na)	4,392	Sulphur (S)	1.9
Potassium (K)	11		12,590
Carbonate radicle (CO_3)	69		
Bicarbonate radicle (HCO_3)	675		

Temperature of water, 64.4° F.

In connection with these wells it may not be out of place to refer briefly to the neighboring mineral springs, which, together with the wells, constitute the most popular health resort in the State. Of these springs the best are the Regent and Siloam springs, both ferromanganese waters, derived from the Pennsylvanian. In the Regent the manganese bicarbonate (16.8 parts per million) aids in the assimilation in the human system of the high percentage of ferrous bicarbonate (58.8 parts per million). The sulphosaline waters of the drilled wells counteract the astringent properties of the ferromanganese waters of the springs, and the two furnish a fortunate combination.

[a] Missouri Geol. Survey, vol. 3, 1892, p. 99.

[b] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

KEARNEY.

The following is a log of a well drilled by A. W. Stubbs Kearney:

Log of well, 6 miles west of Kearney, Clay County.

	Thickness.	De
	Feet.	F
Soil	25	
Limestone	56	
Sandstone	10	
Shale	35	
Sand; water	15	
Limestone	20	
Shale, muddy	28	
Limestone	12	
Shale	6	
Limestone	24	
Shale	6	
Sandstone	12	
Limestone	120	
Shale	22	
Sandstone	22	
Shale	28	
Sandstone	40	
Flinty limestone, dark	10	
Light shale	4	
Brown limestone	4	
Shale	4	
Gray limestone	10	
Black shale	12	
Gray sandstone	12	
Shale	24	
Limestone	6	
Shale	6	
Sandy shale	40	
Sandstone	10	
Thin coal seam	[illegible]	
Shale	12	
Limestone and coal, good	6	
Limestone	[illegible]	
Sandstone	23	
Shale	[illegible]	
Sandstone	18	
Shale	13	
Coarse white sandstone	12	
Blue shale	12	
Sandstone	[illegible]	
Oil sandstone	[illegible]	
Black "slate"	[illegible]	
Sandstone; traces of oil	[illegible]	
Salt sandstone	[illegible]	
Black rotten shale	[illegible]	
Mississippian limestone	[illegible]	

DAVIESS COUNTY.

GALLATIN.

Seven miles east of Gallatin, near the head of a small draw, on the farm of W. C. Macy. Depth, 22 feet; altitude abo about 794 feet; casing, 1¼-inch, 22 feet; temperature of water of air, 82° F.; flow, feeble; date of completion, 1895; bored b hands; cost of well, $25. This well passed through the clay and stone of the Des Moines group. It may be a drift well. On e the sandstone water was struck, which rose 8 feet above the su The flow is uniform. The water is clear and hard and is us watering stock. No analysis has been made.

HARRISON COUNTY.

BETHANY.

About 1 mile west of Bethany, in sec. 16, T. 63, R. 28, on the east bank of Big Creek, is a well owned by the Bethany Improvement Company. Depth, 654 feet; altitude above tide, about 916 feet; casing, 3-inch, 45 feet to rock; flow, 5+ gallons per minute; date of completion, 1885; surface formation, Missouri group. The water is used by the Heilbron Sanitarium. It is said to be especially valuable in rheumatism. It is clear and bubbles with carbon dioxide. The log of the well is as follows:

Log of deep flowing well at Bethany, Harrison County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (45 feet):		
Earth and clay	45	.....
Missouri (53 feet):		
Hard gray limestone	11	56
Dark "slate"	8	64
Limestone	12	76
Dark "slate"	5	81
Gray limestone	17	98
"Marais des Cygnes" shale (Pleasanton) (156 feet):		
Sand shale	81	179
Limestone	5	184
"Soapstone"	4	188
Sand shale	32	220
Slaty shale	18	238
Black slate	1	239
Coal	1	240
Gray "slate"	14	254
Henrietta limestone (149 feet):		
Limestone (coal 4 inches)	3	257
Dark gray "slate"	19	276
Limestone	5	281
"Slate"	4	285
Fire clay	10	295
Limestone	16	311
"Slate" (coal 1 inch)	30	341
"Slate"	29	370
Coal	1	371
"Slate"	32	403
Cherokee shales (251 feet):		
Sand shale	11	414
"Slate"	27	441
Sand shale	9	450
Black "slate"	11	461
Blue clay	3	464
Gray "slate"	3	467
Sand shale	3	470
"Slate" (mixed)	64	534
Dark sandstone	2	536
Black "slate" (coal 7 inches)	16	552
Clay	2	554
"Slate" (mixed)	20	574
Sand shale	62	636
Bowlder	8	644
Sand shale	10	654

It is very probable that the Mississippian would have been reached had the drilling been continued 50 or 60 feet farther. The first flow of water was struck at 200 feet, and it was continuous. The last and strongest flow was reached at the bottom of the well. No analysis of this water has been made.

HOLT COUNTY.

FOREST CITY.

Near Forest City, Holt County, is a deep diamond-drill prospecting well, made in 1901. The core is preserved at the office of the State geological survey, at Rolla, Mo.

Log of prospecting well near Forest City, Holt County.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Pleistocene (65 feet):				
Sandy clay	65	0	65	0
Missouri (866 feet):				
Clay and bowlders	10	0	75	0
Clay shale	15	0	90	0
Blue shale	4	0	94	0
Limestone	5	7	99	7
Fossiliferous limestone	1	5	101	0
Blue shale	3	6	104	6
Limestone	11	0	115	6
Blue shale	4	0	119	6
Limestone	3	6	123	0
Limestone	2	6	125	6
Blue shale	16	6	142	0
Blue limestone	4	3	146	3
Clay shale	3	9	150	0
Blue shale	10	0	160	0
Limestone	30	0	190	0
Bark blue shale	3	0	193	0
Limestone	2	6	195	6
Blue shale	12	6	208	0
Limestone	8	0	216	0
Sand shale	17	0	233	0
Limestone	4	8	237	8
Blue shale	12	8	250	4
Sandstone, shale partings	54	8	305	0
Blue sand shale	16	0	321	0
Dark blue shale	14	0	335	0
Clay shale	33	0	368	0
Blue shale	50	0	418	0
Limestone	27	0	445	0
Black shale	9	0	454	0
Limestone	2	0	456	0
Shale	12	0	468	0
Limestone	20	0	488	0
Black shale	2	0	490	0
Limestone	10	6	500	6
Sand shale	2	0	502	6
Sandstone	3	0	505	6
Blue shale	3	0	508	6
Limestone	4	6	513	0
Dark shale	2	0	515	0
Limestone	7	0	522	0
Sandy shale	3	6	525	6
Dark shale, mixed with limestone	16	6	542	0
Limestone	15	0	557	0
Blue shale	1	9	558	9
Black "slate"	1	5	560	2
Blue shale	12	10	573	0
Limestone-conglomerate	5	6	578	6
Blue shale	4	0	582	6
Limestone	3	6	586	0
Conglomerate	9	6	595	6
Dark shale	1	0	596	6
Limestone	7	0	603	6
Black shale and limestone	3	0	606	6
Limestone-conglomerate	13	10	620	4
Bastard limestone and shale	7	10	628	2
Blue shale	4	3	632	5
Clay	2	1	634	6
Limestone	34	2	668	8
Shale	6	2	674	10
Limestone	23	2	698	0
Dark shale	3	2	701	2
Limestone and shale	2	5	703	7
Black shale	3	4	706	11
Shale and limestone	3	5	710	4
Shale and limestone	1	4	711	8

Log of prospecting well near Forest City, Holt County—Continued.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Missouri—Continued.				
Limestone	13	0	724	8
Dark shale	1	3	725	11
Sand shale	4	0	729	11
Dark shale	1	0	730	11
Coal, poor		6	731	5
Clay to dark shale	3	0	734	5
Limestone	4	2	738	7
(Iron pyrites 737 feet 6 inches to 740 feet.)				
Sandstone	3	2	741	9
Clay shale	5	2	746	11
Sandstone and a little shale	4	6	751	5
Sandstone and shale	1	4	752	9
Dark shale	13	11	766	8
Limestone	2	4	769	0
Dark shale	2	4	771	4
Limestone	3	10	775	2
Clay, shale, and a little limestone	3	10	779	0
Limestone	3	2	782	2
Dark shale	1	0	783	2
Clay shale	3	11	787	1
Clay shale and fragments	4	6	791	7
Limestone	4	10	796	5
Limestone and black shale	2	2	798	7
Black shale		10	799	5
Sandy shale	7	0	806	5
Clay shale, broken and soft	[a] 4	9	843	11
Limestone	5	5	849	4
Shale	16	11	866	3
Sandstone, fossiliferous	5	2	871	5
Sand and shale	10	0	881	5
Shale	1	4	883	4
Blue fossiliferous limestone	3	6	886	10
Blue shale with 8-inch vertical seam (silica)	2	6	889	4
Coal, fair quality		4	889	8
Sandstone	5	6	895	2
Shale	4	3	899	5
Limestone	8	11	908	4
Shale	8	4	916	8
Clay shale and lime	3	0	919	8
Limestone	2	9	922	5
Blue shale, last foot fossiliferous	4		926	5
Limestone, last 6 inches fossiliferous	2	6	928	11
Blue shale, with a little sandstone	1	3	930	2
Des Moines (690 feet):				
Blue limestone		8	930	10
Black shale, with a little thin sandstone	3	3	934	1
Clay shale, broken	2	9	936	10
Alternating sandstone and shale	14	2	951	0
Sand shale, broken	9	10	960	10
Blue shale	23	6	984	4
Fossiliferous sandstone	1	10	986	2
Coal, poor		4	986	6
Blue shale	6	4	992	6
Sandy shale	1	9	994	7
Coal, poor	1	2	995	9
Clay shale	1	4	997	1
Sandstone	5	0	1,002	1
Dark shale	8	11	1,011	0
Carbonaceous shale		5	1,011	5
Clay shale	4	0	1,015	5
Blue shale, a few lime nodules	5	9	1,021	2
Shale	15	1	1,036	3
Limestone		9	1,037	0
Black slate	1	8	1,038	8
Coal, fair quality	1	3	1,039	11
Clay shale	3	1	1,043	0
Blue limestone	2	0	1,045	0
Sandstone	3	10	1,048	10
Sand shale	5	5	1,054	3
Black shale	3	8	1,057	11
Coal, poor	1	0	1,058	11
Sandstone	4	4	1,063	3
Black shale	7	0	1,070	3
Coal, poor		9	1,071	0
Clay shale, soft	2	9	1,073	9
Clay, with some limestone	4	6	1,078	3
Shale	6	2	1,084	5
Clay shale, with sandstone and limestone	1	9	1,086	2

[a] Error in original record; probably should be 37 ft. 6 in.

Log of prospecting well near Forest City, Holt County—Continued.

	Thickness.		Depth.	
	Ft.	in.	Ft.	in.
Des Moines—Continued.				
Sandstone, hard, fine-grained	8	2	1,094	4
Soft, dark shale		4	1,094	[illegible]
Sandstone, shale partings	12	6	1,107	2
Dark shale, with sandstone partings	9	9	1,116	11
Shale	24	1	1,141	0
Coal, poor, with iron pyrites		9	1,141	9
Shale	18	0	1,159	9
Sandstone	5	9	1,165	6
Shale	7	4	1,172	10
Dark shale; a little pyrites at 1,182 feet 4 inches	10	0	1,182	10
Sandstone		6	1,183	4
Dark shale	3	4	1,186	8
(Block for waste in drilling out last core)	2	2	1,188	10
Sand shale	2	0	1,190	10
Shale, dark and slaty	16	1	1,206	11
Shale, with limestone nodules		3	1,207	2
Shale	7	2	1,214	4
Sandstone	1	3	1,215	7
Shale; iron pyrites from 1,216 to 1,217 feet	8	2	1,223	9
Sandstone, with some limestone	4	0	1,227	9
Soft shale		10	1,228	7
Carbonaceous shale		9	1,229	4
Blue shale		8	1,230	0
Hard, sandy shale	2	8	1,232	8
Hard gray shale	3	9	1,236	5
Blue shale	15	1	1,251	1
Coal		5	1,251	16
Blue shale		9	1,252	8
Gray shale, with coal partings; nearly 45° to axis of core		9	1,253	5
Shale	10	0	1,263	5
Coal		3	1,263	8
Light bluish sandstone	13	11	1,277	7
Blue shale	3	9	1,281	4
Sandstone	4	10	1,286	2
Coal		3	1,286	5
Sandstone	57	5	1,343	10
Blue sandy shale	3	2	1,347	0
Dark shale	9	5	1,356	5
Sandstone, coarse-grained, hard	1	1	1,357	6
Dark shale, slaty and hard	3	6	1,361	[illegible]
Sandstone	20	6	1,381	[illegible]
Dark shale	3	0	1,384	6
Coal		5	1,384	[illegible]
Shale	5	2	1,390	[illegible]
Coal		10	1,390	[illegible]
Soft clay shale, irregular cleavage	1	1	1,392	6
(Block for wasted core)	1	4	1,393	4
Shale	6	9	1,400	1
Blue shale, turning to gray sandstone in last foot	17	0	1,417	1
Sandstone	6	0	1,423	1
Fossiliferous sandstone	2	3	1,425	4
Sandstone	9	6	1,434	10
Shale	5	11	1,440	9
(Pine block for wasted core)	3	0	1,443	9
Sandstone, gray, medium to coarse grained	2	1	1,445	10
Blue shale	4	2	1,450	0
"Steatite" 3 inches, blue shale 6 inches, sandy shale 6 inches	1	3	1,451	3
Blue shale, sometimes sandy	14	9	1,466	[illegible]
Black shale, similar to above	14	0	1,480	[illegible]
Dark shale, cleavage up to 35° of core axis	4	8	1,484	[illegible]
Blue shale	4	0	1,488	[illegible]
Coarse gray sandstone with a little limestone	4	9	1,493	5
Clay shale	2	4	1,495	9
Gray sandstone	4	3	1,500	[illegible]
Sandstone	6	8	1,506	[illegible]
Black shale; patches of sandstone at 1,511 feet 4 inches	11	6	1,518	[illegible]
Sandstone	10	6	1,528	[illegible]
Hard, sandy shale	1	4	1,530	[illegible]
Coal		2	1,530	[illegible]
Sandstone, light, with two steatitic partings	4	0	1,534	[illegible]
Sandy shales, with partings of white sandstone	5	10	1,540	[illegible]
Shale and sandstone	3	1	1,543	1
Light-blue shale, with thin streaks of white sandstone	8	8	1,551	[illegible]
Sandstone, light blue	3	8	1,555	[illegible]
Sandstone and shale	1	11	1,557	[illegible]
Shale	2	8	1,560	[illegible]
Light sandstone, fine grained and hard	6	0	1,566	[illegible]
Blue shale with steatite sections and partings, and some diagonal displacements, with highly polished surfaces	14	0	1,580	0
Sandstone, coarse, irregular, with iron pyrites, mica granules, and small fossil fragments	2	0	1,582	[illegible]

Log of prospecting well near Forest City, Holt County—Continued.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Des Moines—Continued.				
Blue shale, sandy and harder in last foot	4	2	1,586	2
Fossiliferous sandstone	1	6	1,587	8
Fossiliferous sandy shale, with horizontal partings	2	4	1,590	0
Blue shale, with vegetable remains; iron pyrites at 1,602 feet 2 inches, 1,605 feet 9 inches, 1,608 feet 1 inch, and 1,608 feet 10 inches	21	5	1,611	5
Shale and sandstone, with vegetable partings	1	10	1,613	3
Fine-grained sandstone, parting freely into small, clear crystals	3	7	1,616	10
Sandstone with a little limestone	3	3	1,620	1
Mississippian (293 feet):				
Limestone (marble ?) with some sandstone	10	0	1,630	1
Blue limestone	3	5	1,633	6
Sandstone and limestone	2	10	1,636	4
Limestone	3	10	1,640	2
Limestone with many partings	20	0	1,660	2
Limestone	8	6	1,668	8
Limestone, with several masses of quartz up to 7 inches in diameter	11	5	1,680	1
Ragged quartz and limestone	11	5	1,691	6
Sandy shale and limestone	1	5	1,692	11
Limestone and sandstone	5	1	1,698	0
(Block for wasted core)	2	0	1,700	0
Limestone with thin partings	18	6	1,718	6
Blue shale with horizontal partings	1	6	1,720	0
Limestone with few partings; fossils from 1,738 feet 8 inches to 1,740 feet	30	0	1,750	0
Hard, light limestone, with fossils and quartz crystals	10	0	1,760	0
Limestone, with irregular partings at 1,761 feet and 1,778 feet 6 inches to 1,780 feet	20	0	1,780	0
Limestone	2	5	1,782	5
Very hard quartzite		7	1,783	0
Limestone	11	6	1,794	6
Chert		2	1,794	8
Sandy limestone		10	1,795	6
Chert		9	1,796	3
Hard and sandy limestone	1	8	1,797	11
Broken chert and limestone		10	1,798	9
Limestone, sandy and hard	1	3	1,800	0
Fossiliferous limestone	1	6	1,801	6
Chert		3	1,801	9
Fossiliferous limestone	1	5	1,803	2
Chert ending in quartzite	1	0	1,804	2
Magnesian limestone; quartz at 1,805 feet 6 inches	5	10	1,810	0
Limestone, chert, and quartzite, with fossils	3	7	1,813	7
(Block for wasted core)	7	5	1,821	0
Sandstone, light, with some lime	1	3	1,822	3
Bluish sandstone, with lime	7	9	1,830	0
Sandstone, bluish, lime increasing	7	0	1,837	0
Limestone	3	0	1,840	0
Limestone with some marble (?); a few spots of sandstone and chert	73	5	1,913	5
Devonian (128 feet):				
Blue shale mixed with a little lime	6	7	1,920	0
Sandy shale	3	10	1,923	10
Shale, blue, green-brown, and red, containing iron oxide	80	4	2,004	2
Shale, with lime	19	10	2,024	0
Shale, fine grained, increasing in hardness	16	0	2,040	0
Blue shale	1	1	2,041	1
Silurian (359+ feet):				
Fossiliferous limestone	16	9	2,057	10
Blue shale	4	9	2,062	7
Limestone	17	5	2,080	0
Limestone, some thin partings	40	0	2,120	0
Limestone, "half-inch shale"	23	0	2,143	0
Limestone	19	5	2,162	5
White and blue chert		4	2,162	9
Limestone	34	3	2,197	0
Coarse limestone; cavities lined with quartz crystals	3	0	2,200	0
Limestone	80	00	2,280	0
Dark-gray limestone, sandy, hard	13	10	2,293	10
Limestone; many cavities; black-shale partings	7	3	2,301	1
Limestone; 2 inches of chert and quartz at 2,335 feet 7 inches	18	11	2,320	0
Limestone, white, fine grained	12	2	2,332	2
Limestone; small quartz crystals in last 4 feet	7	10	2,340	0
Limestone; many cavities, often with small quartz crystals; occasional spots of chert	10	0	2,350	0
Gray limestone, chert increases	1	4	2,351	4
Dark limestone, some chert	2	0	2,353	4
Dark limestone, sharp sand with fossils	6	8	2,360	0
Limestone; solution cavities and fossil molds abound	40	0	2,400	0
(No return of water below 2,350 feet.)				

LINN COUNTY.

BROOKFIELD.

A shaft and boring at Brookfield gave the following section:

Section of shaft and boring at Brookfield, Linn County.

	Thickness.	
	Ft.	*in.*
Surface deposits (the rhomboidal limestone should have come in here, 17 feet below the surface, but for some reason it was not found)	30	0
Hard rock, next below No. 42, and found in the bed of the creek near by	1	10
Fire clay and shales	16	0
"Soapstone"	25	0
Coal (Nutter's)	1	3
Fire clay and shales	14	0
Concretions	6	0
Hard rock	1	8
"Soapstone"	52	8
Coal (working seam)	2	4
Brown fire clay and shales	16	0
Concretions	14	0
Fire clay	10	0
Sand rock (lowest rock at Joabs Creek)	8	0
Fire clay	3	0
"Soapstone"	4	0
"Slate"		8
Fire clay (bottom of shaft)	5	0
Below this a boring penetrated the following:		
"Soapstone"	8	0
Fire clay	4	0
"Soapstone"	14	0
Fire clay	4	0
"Soapstone"	2	0
Coal	2	1
Fire clay		5
Coal		6
Fire clay and shales	15	0
Sandstone	8	0
"Soapstone"	10	0
Hard rock; pyrites		[illegible]
"Soapstone"	10	0
"Slate" and shales		[illegible]
Concretions	1	0
Hard rock (not bored through)	2	[illegible]

ST. CATHERINE.

A shaft and boring at St. Catherine showed the following se[illegible]

Section of shaft and boring at St. Catherine, Linn County.

	Thickness	
	Ft.	[illegible]
Clay	14	[illegible]
Rotten "slate"	[illegible]	[illegible]
Flinty sandstone	[illegible]	[illegible]
Coal	[illegible]	[illegible]
Clay	[illegible]	[illegible]
"Soapstone"	22	[illegible]
Hard limestone	[illegible]	[illegible]
Blue sand	[illegible]	[illegible]
"Soapstone"	[illegible]	[illegible]
Coal (bottom of shaft)	[illegible]	[illegible]
Below this a boring was made and passed through the following:		
Fire clay	[illegible]	[illegible]
Hard, flinty sand rock	[illegible]	[illegible]
"Soapstone"	[illegible]	[illegible]
Black "slate"	[illegible]	[illegible]
Coal	[illegible]	[illegible]
Fire clay	[illegible]	[illegible]
"Soapstone"	[illegible]	[illegible]
Coal	[illegible]	[illegible]

[a] This section and the one at Brookfield are taken from Broadhead, G. C., Missouri [illegible] Vol. 1, 1874, p. 267.

LIVINGSTON COUNTY.

CHILLICOTHE.

About 3 miles from Chillicothe, in sec. 28, T. 58, R. 23, is a gas prospect hole whose mouth is at an altitude of about 825 feet. The following log has been furnished by Mr. R. Hawkins, of Chillicothe:

Log of gas prospect hole about 3 miles from Chillicothe, Livingston County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (56 feet):		
Yellow clay	0	30
Soft yellow sandstone	15	45
Light-colored shales	11	56
Des Moines (425 feet):		
Hard conglomerate; cased from top, 8¼ inch	2	58
Black "slate"	3	61
Soft light-colored gray shales	69	130
Sandstone, with 6-inch coal	3	133
Light-colored shales	57	190
Black "slate"	4	194
Gray shales	36	230
Red and greenish-gray shale; caved	8	238
Dark shales with barren coal seam; cased from top, 7½-inch	13	251
Limestone	1	252
Gray shales	45	297
Brown "smut"	3	300
Drab and purple clays and shales, with coal particles	48	348
Soft, nearly white sandstone, rounded grains	3	351
Black sand shales; saline water at 406 + feet	79	430
Porous conglomerate; saline water	12	442
White, plastic fire clay	10	452
Sandy coal and fire clay, gray to purplish	29	481
Keokuk and Burlington (319 feet):		
White, very hard, flinty limestone	3	484
Soft white limestone, with flinty layers and a soft white substance (gypsum?) not a carbonate	38	522
Sandstone, fire clay, "slates," and pebbles; saline water	62	584
Soft, chalky limestone	12	596
Flint or quartzite sandstone, shales, etc	6	602
Black shales, very little lime	14	616
Soft sandy gray calcareous rock	20	636
White and blue calcareous shales and flint	9	645
Soft sandy gray calcareous rock	69	714
Dark plastic to hard joint clay, caved badly; cased, 4½ inch, at 762 feet	48	762
White limestone	4	766
Dark "hydraulic" limestone	13	779
Pure, soft white limestone	21	800
Chouteau (81 feet):		
Brownish mealy limestone; saline water	46	846
Crystalline limestone	8	854
Dark impure limestone; saline water	27	881
Hannibal formation (101 feet):		
Fine yellowish-gray lime sand	25	906
Light to dark gray limestone, with some yellowish sand	11	917
Gray to orange sandstone, with some lime; gas	65	982
Devonian (94 feet):		
Limestone, with black organic matter	8	990
Limestone, with gray sandstone at top	75	1,065
Fine brown lime sand, with pyrite, etc	11	1,076
St. Peter sandstone (25 + feet):		
Hard quartzite	20	1,096
Pure white sand, with saline water; caved	5	1,101

UTICA.

In sec. 2, T. 25, R. 56, in the valley of a small branch which empties into Shoal Creek, about 5 miles southwest of Utica, Livingston County, is a well owned by G. H. Lawson. Depth, 421 feet; altitude above tide, about 660 feet; casing, 5⅝ inch; 400 feet (partially cased); temperature of water, 59° F.; of air, 76° F.; flow, weak; date of completion, 1897; driller, C. P. Thomas, of West Bend, Iowa; cost of well, $1,000; surface formation, lower Pennsylvanian. The principal

source of the water is at a depth of 360 to 370 feet, in the soft basal sandstone of the Cherokee shales. A nonflowing vein of water was reached at a depth of 35 feet. The present flow is feeble, the water rising only about 10 feet above the surface. The well was sunk to obtain water for stock, but the flow was so weak—only about 40 barrels per day—that the owner put in a $1,500 pumping plant. The water is saline, with a small amount of hydrogen sulphide and some iron, which is precipitated around the well. No record was kept. The drill, however, passed through the Des Moines into the Mississippian. The following is a copy of the analysis of this water made by Professor Schweitzer, no date being given:

Analysis of water of Lawson well, near Utica, Livingston County.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	13	Potassium (K)	45
Iron (Fe)	10	Sulphate radicle (SO_4)	1,289
Calcium (Ca)	312	Chlorine (Cl)	4,250
Magnesium (Mg)	136		
Sodium (Na)	2,728		8,783

This water, though strongly saline, is said to be excellent for stock, and is a good example of the waters that are derived from the base of the Cherokee shales.

MERCER COUNTY.

WASSON CREEK.

Two and one-half miles south of Lineville, Iowa, in Mercer County, Mo., in the east half of lot 2, NW. ¼ sec. 1, T. 66, R. 24, in a valley about 100 feet from Wasson Creek, is a well owned by M. B. Haver & Son. Depth, 153 feet; altitude above tide, about 672 feet; depth of casing, 27 feet; temperature of water, 53° F.;[b] of air, 65° F.; flow feeble; date of completion, 1879; driller, J. H. Reger, Lineville; cost, $150; surface formation, Des Moines, under Pleistocene.

The partial record of this well which follows was given from memory by the driller:

Log of Haver well in Mercer County, near Lineville, Iowa

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Pleistocene	27	0	27	0
Blue bastard limestone	1	0	28	0
"Marias des Cygnes" shales (Pleasanton) (125 feet):				
"Soapstone"	8	0	36	0
Gray "slate"	35	0	71	0
Coal		2	71	2
Fine clay		5	71	7
Sandstone	3	0	74	7
Gray "slate"	30	0	104	7
Coal		3	104	10
"Slate" and thin coal seams	45	2	150	0
Sandstone	3	0	153	0

[a] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

[b] In Swetzer's report on Mineral Waters, vol. 3, Missouri Geol. Survey, 1892, p. 128, A. E. Woodward gives the temperature of this well in 1892 as 52° F., air temperature 71° F.

It is possible that the 1 foot of limestone is the base of the Missouri group. At the bottom of the well the drillers struck a quicksand that was so difficult to penetrate that they stopped work. Water was struck at 27 feet and in the sandstone at 150 feet. The water came up slowly during the night and flowed gently over the top of the pipe. The flow, although constant, is very feeble when not pumped. The analysis here given was made by Woodward and Schweitzer:[a]

Analysis of water from Haver well, near Lineville, Iowa.[b]

	Parts per million.		Parts per million.
Silica (SiO_2)	2	Potassium (K)	16
Aluminum (Al)	2.6	Sulphate radicle (SO_4)	2,245
Calcium (Ca)	9.6	Chlorine (Cl)	171
Magnesium (Mg)	11		
Sodium (Na)	1,047		3,504.2

This water has a local reputation and is shipped to various points. It is esteemed as especially valuable for constipation and stomach and kidney troubles. Schweitzer places this well in the Glauber salt (sodium sulphate) group of the sulphatic waters, or those containing sulphates as their main constituents. He has shown that dolomitic limestone containing gypsum, as associated with marls rich in alkalies, or other rocks containing alkaline carbonates or silicates are favorable for the formation of Glauber salt springs or wells.

About 250 feet southwest of the Haver well is a well owned by J. H. Reger. Depth, 158 feet 8 inches; altitude above tide, about 680 feet; temperature of water, 54° F.; of air, 65° F.; water rises nearly to the surface; date of completion, February, 1892; driller, J. H. Reger; surface formation, Des Moines, under Pleistocene. The water is strongly chalybeate, and in this respect differs from that of the Haver well, which contains no iron. It is valued as a tonic and in kidney troubles.

A well in the immediate vicinity owned by J. S. Haymaker has a depth of 202 feet; altitude above tide, 672 feet; casing, 6-inch, 92 feet; temperature of water, 53° F.; of air, 65° F.; water rises nearly to the surface; date of completion, March, 1902; drillers, Frank Bowles and Ed Jumper; cost, $250; surface formation, Des Moines, under Pleistocene. The first water was struck at a depth of 134 feet and rose within 26 feet of the top of the well; a second vein of water was struck at a depth of 175 feet which rose within 23 feet of the surface. The log of this well corresponds to that of the Haver well; the water also is similar and apparently has the same composition.

[a] Missouri Geol. Survey, vol. 3, 1892, p. 128.

[b] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

PRINCETON.

The following record of a well 10 miles southeast of Princeton, Mercer County, was obtained by Mr. R. Hawkins, of Chillicothe:

Log of well 10 miles southeast of Princeton, Mercer County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (180 feet):		
Clay	180	180
Des Moines (321 feet):		
Hard rock, about	10	190
Conglomerate	30	220
Not reported	20	240
Coal	4	244
Hard white sand rock	13	257
Coal	5	262
Shales	3	265
Not reported	236	501

No water was obtained.

NODAWAY COUNTY.

BURLINGTON JUNCTION.

At Burlington Junction, Nodaway County, one-half mile south of the Chicago, Burlington and Quincy Railway station, is a well owned by the Nodaway Valley Oil, Gas, and Mineral Company. Elevation of curb, 969 feet; driller, Sherman Burdick; date of completion, 1905; kind of water, saline. The following log is taken from the original record of J. N. Maupin:

Log of the well of Nodaway Valley Oil, Gas and Mineral Company, Burlington Junction, Nodaway County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (68 feet):		
Soil	68	68
Missouri (910 feet):		
Coal	.....	68
Blue shales	459	527
Yellow ocher	18	545
Sand shells	100	645
Salt sand	20	665
Lime shells	30	695
Shale	40	735
Hard blue limestone	30	765
Lime shells	15	780
Shale	66	846
Limestone	25	871
Shale	40	911
Limestone	15	926
Shale	30	956
Limestone	20	976
Brown sand	2	978
Des Moines (722 feet):		
White Trenton rock	117	1,095
Gas sand	30	1,125
Black shale	114	1,239
Brown sand	1	1,240
Black shale	17	1,257
White "talc"	3	1,260
Lime shells	10	1,270
Black shale	300	1,570
Lime shells	30	1,600
Black shale sand	40	1,640

Log of the well of Nodaway Valley Oil, Gas and Mineral Company, Burlington Junction, Nodaway County—Continued.

	Thickness.	Depth.
Des Moines—Continued.	*Feet.*	*Feet.*
Black shale and sand mixed	30	1,670
Red Dakota sand	2	1,672
Black shale and fine sand	20	1,692
Brown sand	5	1,697
Black shale, sand, peacock colors, and traces of oil	20	1,717
Mississippian (186+ feet):		
Lime sand	11	1,728
Pebble sand	10	1,738
Red Trenton rock or cap rock	165	1,903

This well was sunk for oil, and no record was kept of water horizons.

MARYVILLE.

On the west side of the road leading north from the Burlington Railway station, in the NE. ¼ SE. ¼, sec. 17, T. 64, R. 35, is a well owned by Miss Alice Beal. This well is about 15 feet above the level of the railroad track. It was drilled in 1884 by Thomas Brown, of the Diamond Drill Company, Chicago, Ill., to a depth of 1,003 feet. It has a 4-inch bore, and is cased 300 feet to solid rock. A good vein of water was struck at 600 feet. The driller's record book was loaned to the Missouri State geologist in 1885 and was subsequently lost.

SOUTH-CENTRAL DISTRICT.

GENERAL ARTESIAN CONDITIONS.

The south-central district includes the area between the Atchison, Topeka and Santa Fe Railway and a line running from Kansas City through Sedalia, Versailles, and along Osage and Missouri rivers to Warren County, thence northward along the ridge that bounds the northeast district to Iowa. Geologically this district is divided by Missouri River into two well-marked sections. Except for narrow patches of Mississippian in Harrison and Boone, the Pennsylvanian rocks underlie the northern section. The great dividing ridge, or northeastern extension of the Ozark dome, running across the northern half of the State, dips gently to the northwest, although it is broken here and there by slight anticlinal folds and disturbances. Flowing wells are generally confined to the area along Missouri River, where erosion has cut down the surface to such a degree that there is sufficient head for the underground water. South of Missouri River, Cambrian rocks are exposed on the west slope of the Ozark dome, but the dip to the northwest brings successively to the surface the Mississippian, Des Moines, and Missouri rocks. Along this slope, which is decidedly broken and disturbed in Saline and Cooper counties, conditions are favorable for artesian waters. The development of anticlinal folds along the western side of the Ozark Mountains has left its impress on the topography and especially on

the course of the rivers. An anticline that enters Missouri from Kansas just south of Kansas City has deflected Missouri River at that point from a southerly to an easterly course, across several anticlinal ridges with a northeast-southwest strike, which pass from Vernon County through Saline County and deflect Missouri River to the north. One of these axes is well defined one-fourth of a mile east of Napton, on the Missouri Pacific Railway, and near Lisbon, on the other side of the river, the continuation of the axis is exposed. At Higbee a well 300 feet deep reached the Mississippian series at 240 feet, showing that one of these anticlinal folds probably stands near this point. It is likely that this anticline has an important bearing on the saline waters of Saline and Howard counties. There are flowing wells at or near the following places: Brunswick and Salisbury, Chariton County; Randolph Springs, Randolph County; Malta Bend and Sweet Springs, Saline County; Boonslick and Fayette, Howard County; Sedalia and Smithton, Pettis County; Fortuna, Moniteau County; Olean, Miller County; California, Moniteau County; Cedar City, Callaway County, and in southeastern Cole County.

AUDRAIN COUNTY.

MEXICO.

At Mexico, Audrain County, the waterworks company drilled a well 1,025 feet deep to supply the city with water. The altitude of Mexico, at the Chicago and Alton Railway station, is 811 feet. The following log was obtained:

Log of waterworks company well, Mexico, Audrain County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (15 feet):		
Soil	15	15
Des Moines (130 feet):		
Limestone and fragments of gray quartz or gravel	10	25
Limestone, soft, drab, earthy	10	35
Limestone, darker and harder, with black shale	15	50
Black shale	2	52
Limestone, soft, light bluish gray	13	65
Shale, black, bituminous	5	70
Limestone, fine grained, with fragments of black shale	50	120
Limestone, fine grained, soft, light gray, no shale	20	140
Coal, bituminous	5	145
Mississippian (420 feet):[a]		
Chert, hard, gray, yellowish coating on some fragments	15	160
Chert, hard, gray hornstone, some white and opaque	40	200
Limestone with some chert and shale	250	450
Sandstone, rounded, white, translucent quartz grains; some limestone and chert	80	530
Limestone, soft, gray, earthy	35	565
Limestone, soft, gray, with green shale	65	630
Sandstone, white quartz, chert, limestone and shale	40	670
Limestone, gray, compact, earthy; some shale	10	680
Chert, white, iron stained; a few grains of quartz sand	25	705
Limestone, compact, earthy; some shale and chert	135	840
Chert; some limestone and shale	20	860
Limestone and soft yellowish-white powder	10	870
Sandstone, white quartz, with considerable limestone	10	880
Limestone, soft, gray	90	970
Limestone in soft white powder	55	1,025

[a] The correlation below 565 feet becomes too uncertain to be of any value.

The following is a sanitary analysis of water from this well, made by Prof. Charles R. Sanger, of Washington University, St. Louis:

Sanitary analysis of water from waterworks well, Mexico, Audrain County.

[Samples collected October 5, 1896.]

	Parts per million.		Parts per million.
Total residue from unfiltered water	531	Chlorine	45.7
Loss on ignition from unfiltered water	52	Permanent hardness	None.
Fixed residue from unfiltered water	479	Temporary hardness	275
Total residue from filtered water	479	Lime (CaO)	99.5
Loss on ignition from filtered water	42	Magnesia (MgO)	52.5
Fixed residue from filtered water	437	Alkali carbonate	54.8
Nitrogen as free ammonia	558	Turbidity, slight.	
Nitrogen as nitrates	.06	Sediment, very slight.	
Oxygen consumed	98	Color, none.	
		Taste, slightly alkali.	
		Odor, none.	
		Bacteria after 96 hours culture, 378 per cubic centimeter.	

VANDALIA.

There are about 45 drilled wells near Vandalia, Audrain County, varying from 120 to 450 feet in depth. It has been impossible to obtain the logs of any of these wells, but it is stated that they furnish an abundance of water for stock and farm purposes, and that water rises within 25 to 75 feet of the surface. The water-bearing formations in these wells are usually gravel or sandstone, and the water is commonly hard, with occasionally some sulphur.

BOONE COUNTY.

COLUMBIA.

Two miles northeast of Columbia, Boone County, is a well owned by the city of Columbia and drilled by Cliff Rummons. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of well near Columbia, Boone County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soft yellow clay	40	40
White lime	40	80
Soapstone blue, with gravel	4	84
Blue shale, light in color	36	120
Shale, mundic, some sand mixed; caving; casing driven from 300 to 450 feet	330	450
Blue lime rock, easy drilling	100	550
Blue flint rock, with crevices and a light showing of zinc ore	25	575
White sand and lime rock	100	675
Soft light flint rock	85	760
Open crevice; full of water, which was analyzed at Missouri University and proved to be of a fine quality	15	775
White and blue flint	25	800

CALLAWAY COUNTY.

CEDAR CITY.

A well at Cedar City, owned by F. M. Pease & Co., of Chicago, was drilled by Charles York, of Allentown, Allegany County, N. Y. It is situated in a stream bed about half a mile from the Missouri River bottoms, at an altitude of about 560 feet. It was drilled to a depth of 1,282 feet, with a 10-inch bore, and completed in 1902. Water was found in sand, and flowing water was reached at depths of 182, 220, and 423 feet. The flow from the 423-foot level was strong. The force increased at 700 and 800 feet and was strongest below 1,200 feet. Mr. S. W. Cox states that the flow was so strong at 1,282 feet that the drill could make no headway, and work was stopped. The water is clear, cold, and soft. The drilling was started in the Jefferson City limestone.

FULTON.

At Fulton, Callaway County, there are a number of deep wells, from two of which the city derives its water supply. Well No. 1 was drilled in 1888 to a depth of 785 feet with a 9-inch bore. Well No. 2 was drilled in 1895 to a depth of 703 feet with a 9-inch bore. The following information was secured through the kindness of Mr. D. K. Greger, of Fulton:

The temperature of the water from these wells is 58° F., the air temperature 72° F. The altitude is 814 feet above tide. A strong flow was struck at a depth of 450 feet. The well was cased to this depth, and the water rose within 240 feet of the surface. Both of these wells are located inside of the pump house, and they obtain water from the same bed, as when No. 2 was drilled below 450 feet the cuttings caused the water in No. 1 to be discolored. The stratum struck at 450 feet was the St. Peter sandstone. As the beds dip north by northwest this formation comes to the surface toward the southeast in the Ozarks. The following log gives the record for both of these wells:

Log of wells Nos. 1 and 2, Fulton, Callaway County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (40 feet):		
Soil, clay, shale, shaly sandstone	40	40
Graydon sandstone (80 feet):		
Graydon sandstone conglomerate	80	120
Burlington (20 feet):		
Limestone, light gray	12	132
Limestone, red-brown	8	140
Kinderhook (3 feet):		
Sandy, yellow shale	3	143
"Hamilton"[a] (70 feet):		
Shale, white, in cuttings	31	174
Limestone	39	213

[a] This Hamilton has been described by D. K. Greger (Am. Geologist, vol. 12, 1893, p. 204) from outcroppings in the county. Mr. Greger further states that the Chouteau limestone is not developed in this region; that the Trenton and Hudson River are likewise missing; and that the Devonian rests directly on the magnesian series—in some places on the Joachim limestone and in others on the St. Peter sandstone.

Log of wells Nos. 1 and 2, Fulton, Callaway County—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Joachim limestone (42 feet):		
Buff magnesian limestone	42	255
St. Peter sandstone (120 feet):		
Sandstone	120	375
Jefferson City limestone (214 feet):		
Buff magnesian limestone; strong water at 450 feet	214	589
Roubidoux sandstone (65 feet):		
Sandstone	65	654
Gasconade limestone (131 feet):		
Limestone	[a] 126	780
Sandstone	5	785

The following analysis[a] was made April 5, 1904:

Analysis of water from well No. 1 at Fulton, Callaway County.

	Parts per million.
Total residue after evaporation	531
Chlorine	12.5
Oxygen consumed	1.75
Free ammonia	.48
Albuminoid ammonia	.55
Nitrates	.31
Nitrites	None.

Color, clear.

Odor, none.

Bacteria in 1 cubic centimeter (¼ teaspoonful of water, agar pits counted the third day), 118,115.

Growth of bacteria in beef tea at 40°–42° C., cloudy.

Intra-peritoneal injection of beef-tea culture, incubated at 40° C. for twenty-four hours, killed guinea pig.

At the State hospital No. 1, one-half mile east of Fulton, are two deep drilled wells, one on a hill and one on a plain, 960 and 904 feet deep, respectively. The principal vein of water was found in both at about 800 feet in black porous sandstone. The water rises within 180 feet of the surface.

Another well is located at the deaf and dumb asylum and still another at the tobacco factory, but no data for either of these could be obtained.

CHARITON COUNTY.

BRUNSWICK.

One-fourth of a mile north of the Brunswick city hall, in sec. 3, T. 53, R. 20, on a bluff overlooking Missouri River, is a well owned by S. Benecke & Co. Depth, 1,505 feet; altitude above tide, 712 feet; casing, 8-inch, 600 feet; temperature of water, 53° F.; date of completion, 1887; surface formation, Des Moines. This well was sunk in the hope of obtaining natural gas. As this was not found at a depth of

[a] Bull. Missouri State Board of Health, April, 1904.

1,505 feet, the well was cased to 700 feet, and since then the mineral water has been used for drinking and bathing purposes. The log of the well has been lost. The following information was given from memory by the owner of the well:

Solid Mississippian limestone was struck at a depth of 130 feet, everything down to that point being Des Moines. "At a distance of about 300 feet[a] we struck a very strong salt water, one tin cupful of which when evaporated left a teaspoonful of salt. When we reached 1,400 feet, the water began to flow freely and continued to do so long after we abandoned the well." The flow has, however, been decreasing from year to year, and at present the water stands within 10 feet of the surface. It is probable that the main flow was derived from the St. Peter sandstone at a depth of 1,400 feet. Mr. Benecke further states that a bed of fine white marble was found somewhere in the neighborhood of 900 feet. This was probably dolomite. The following analysis is given by Schweitzer in his report on the mineral waters of Missouri:

Analysis of water from well at Brunswick, Chariton County.[b]

	Parts per million.		Parts per million.
Silica (SiO_2)	5	Bicarbonate radicle (HCO_3)	597
Calcium (Ca)	740	Sulphate radicle (SO_4)	1,304
Magnesium (Mg)	329	Chlorine (Cl)	8,228
Sodium (Na)	4,706		
Lithium (Li)	Trace.		15,909

This water, which is strongly saline and highly charged with sulphureted hydrogen, comes under the second division of Schweitzer's muriatic waters and is somewhat similar to that of the Louisiana well. At one time this well was a popular resort. A bath house, since destroyed, was built, and the water was also used internally because of its aperient qualities. The well cost about $3,500, of which the city paid $2,000 and the citizens the remainder.

SALISBURY.

In the southeastern part of Salisbury, on a gentle southern slope, is a well owned by the city. Depth, 852 feet; altitude, above tide, 740 feet; casing, 6-inch, 100 feet; temperature of water, 58° F.; flow, weak; date of completion, 1896; cost, $2,500; surface formation, Des Moines. The city of Salisbury started this well in 1895 and finished it in 1896. No record of the drilling was kept. It is stated that the drill passed through 6 feet of soft loam, about 70 feet of soft sand, and 60 feet of

[a] This was probably in the Hannibal shales.

[b] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

white sandstone. The first water was reached at 150 feet and the second at 210 feet, both being fresh. At a lower level, below 600 feet, a flow of salt sulphur water was obtained. The flow has not materially changed. The water is used medicinally for drinking and baths. The following is an analysis of this water made by Schweitzer in 1896:

Analysis of water from well at Salisbury, Chariton County.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	21	Lithium (Li)	.56
Iron (Fe)	5	Carbonate radicle (CO_3)	454
Manganese (Mn)	1.2	Sulphate radicle (SO_4)	1,346
Calcium (Ca)	491	Chlorine (Cl)	6,030
Magnesium (Mg)	396	Bromine (Br)	12
Sodium (Na)	3,538		
Potassium (K)	61		12,356

The water is a muriatic water of value. Its salts of iron, manganese, magnesia, and lithium, as well as the bromide, give it therapeutic effects. The source of this water is doubtful. It is greatly to be regretted that the drillers of several important wells in this district have either kept no logs or lost those which were kept.

COLE COUNTY.

EUGENE.

Three miles southwest of Eugene, Cole County, in sec. 13, T. 41, R. 14, is a well owned by the Bell Tunnel Mining Company, and drilled by Charles E. Miller. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of well of Bell Tunnel Mining Company near Eugene, Cole County.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and chert	17	17
Lime, with clay openings, water	38 (?)	55
Hard, blue lime	5	60
Open ground in limewater	5	65
Blue lime and calcite	13	78
Gray magnesia lime with layers of flint at intervals; water stronger as greater depth is reached	158	236

This well is probably in Jefferson City limestone.

MISCELLANEOUS WELLS.

In southern Cole County, and in Miller County adjoining, a number of prospect holes sunk for mineral struck water that rose to the surface. Two of these are located on the farm of Dell Karr, about one-

[a] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

half mile east of Bass post-office on the south line of sec. 31, T. 45, R. 12. One of these wells was 110 feet deep with a 6-inch bore, and was drilled about 1901 by Mr. Groover, of Jefferson City. The water flowed feebly at the surface. Twenty-five feet away another well was sunk to a depth of 50 feet. Both of these probably obtain water from the Gasconade limestone. No log was kept.

One-half mile south of the Karr place, on the farm of Daniel Schreiber, two prospect holes were sunk. In the one in the valley the water rose 5 feet above the casing; but the one on the ridge, about 50 feet higher, did not flow. One-half mile southwest of the Karr place, on the farm of Mrs. Annie Barnhardt, a prospect hole sunk to the depth of 100 feet resulted in a flowing well. One mile due south of the same place Mr. Marstellar has two flowing wells, each about 100 feet deep.

About 2½ miles south of Hickory Hills post-office, on the Wallace Scott property, near the middle of T. 42, R. 13, on Bob Druly Creek, th[illegible] prospect holes within half a mile of each other were sunk to a depth of 100 feet each. These were all 6-inch holes made by a churn drill. Of these wells the one near the mining shaft has a feeble flow; another, a quarter of a mile to the east, is much stronger, and a third, a quarter of a mile to the southeast, gives a good stream of water. The temperature of the water in these wells is 58° F., with the air temperature 93° F. The water is clear, with a slight odor of sulphureted hydrogen. All of these wells probably obtain water from the Gasconade limestone. Another well, three-fourths of a mile northeast of Hickory Hills, obtains flowing water at a depth of 27[illegible] feet.

HOWARD COUNTY.

BOONSLICK.

In a narrow valley a few hundred feet below the old Boonslick salt springs, where Daniel Boone settled and manufactured salt, is a well owned by W. M. Marshall, of Boonesboro. The writer is indebted to Prof. A. F. Hendrix, of Kansas State University, for the log of this well and for assistance in various other ways: Depth, 1,002 feet [illegible] inches; altitude above tide by aneroid barometer, 599 feet; casing, 1½-inch, 400 feet; temperature of water, 62° F., of air, 88° F.; flow, 20 to 30 gallons per minute; date of starting, 1869; of completion, 1872; surface formation, Des Moines, under Pleistocene.

Log of Marshall well, Boonslick, Howard County.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Pleistocene (22 feet):				
Soil (wooden conductor 10 inches square)	22	0	22	0
Des Moines (66 feet 11 inches):				
Flint rock	2	10	24	10
Hard limestone	2	0	26	10
Hard gravel		11	27	9
Soft limestone	2	2	29	11
Dry crevice		7½	30	6½
Hard flint; fresh water	6	9	37	3½
Slate rock		8	37	11½
"Stone coal"	2	6	40	5½
"Slate"		10	41	3½
"Soapstone"	19	6	60	9½
Blue limestone	4	3½	65	1
White limestone; small vein of salt water	3	0	68	1
Soft white limestone	5	6	73	7
Flint bowlder	1	6	75	1
White limestone	6	9	81	10
"Stone coal"		7	82	5
"Soapstone"	4	2	86	7
Flint and limestone	1	2	87	9
"Soapstone"	1	2	88	11
Mississippian (217 feet 1 inch):				
Black flint		5	89	4
Coarse gray limestone	13	7	102	11
White limestone and flint	3	0	105	11
Coarse gray limestone	2	0	107	11
Red flint		5	108	4
Coarse gray limestone	1	7	109	11
White shale, flint	2	10	112	9
Gray limestone and spar	10	4	123	1
Black flint		4	123	5
White limestone	1	6	124	11
Hard white flint	1	1	126	0
Soft limestone		9	126	9
Hard gray flint		7	127	4
Gray limestone	4	0	131	4
Black flint		4	131	8
Gray limestone	1	0	132	8
White flint		4	133	0
White limestone		5	133	5
White flint		3	133	8
White limestone		5	134	1
White sandstone	3	3	137	4
White flint		7	137	11
White sandstone	4	6	142	5
White flint	1	5	143	10
Blue sandstone		9	144	7
White flint	1	3	145	10
White sandstone	1	4	147	2
White sand and flint mixed		8	147	10
Crystallized white flint		9	148	7
Coarse gray sandstone		9	149	4
Blue flint		3	149	7
White sandstone		6	150	1
Blue flint		9	150	10
Brown sandstone		5	151	3
Blue flint		4	151	7
Black sandstone		9	152	4
White limestone and spar	1	3	153	7
Fine white sandstone	1	3	154	10
Blue flint		5	155	3
White sandstone	2	3	157	6
White flint	1	0	158	6
Gray flint	1	3	159	9
White sandstone		9	160	6
Gray flint		6	161	0
White flint; water and gas	3	9	164	9
White sandstone	25	3	190	0
Black sandstone and shale	12	6	202	6
Gray sandstone	9	0	211	6
Coarse sandstone and shale	1	6	213	0
Hard white sandstone	3	0	216	0
Gray sandstone and shale mixed	54	0	270	0
Black and white sandstone and shale	36	0	306	0
Devonian and Cambrian (696 feet):				
Blue sandstone	7	0	313	0
Fine white sandstone	4	0	317	0
Brown sandstone and shale	11	0	328	0
Black sandstone	5	0	333	0
Brown sandstone and shale	9	0	342	0
White flint		9	342	9

Log of Marshall well, Boonslick, Howard County—Continued.

	Thickness.		De
	Ft.	in.	
Devonian and Cambrian—Continued.			
Gray sandstone	13	0	
White flint	8	1	
White sandstone	34	6	
Hard white flint	2	8	
Blue sandstone	1	6	
White sandstone	4	8	
White limestone and flint	3	3	
Sandstone	13	0	
White flint	1	6	
Soft white sandstone	24	0	
White flint	3	0	
Brown sandstone	1	6	
White shaly flint	3	6	
White soft sandstone	3	0	
White flint	5	0	
Sandstone, lime, and flint	9	9	
Blue sandstone	8	0	
White sandstone and shale; salt water; stream increased one-third at 482 feet 1 inch	1	3	
Sandstone	21	0	
White sandstone and flint	11	0	
White "cotton rock"	5	0	
Soft white sandstone	31	0	
Blue flint bowlder	1	3	
White sand and flint	4	6	
Blue sandstone and shale	23	0	
White sand and flint	21	0	
White sandstone	5	0	
White flint	2	6	
White sandstone	34	0	
White shaly flint	6	3	
Soft white sandstone; small addition of water, very strong and offensive with gas	61	0	
Sandstone	262	0	
Coarse white sandstone; fresh water said to have come in here	31	0	1,
Crevice		9	1,

The water from this well is strongly saline and highly charged sulphureted hydrogen. The ground around the ditch is covered a black and white deposit. When visited by the writer, July 1904, the well had an estimated flow of 20 gallons per minute. following data were obtained: At 37 feet water was obtained; a feet weak salt water; at 164 feet 9 inches the size of the strean increased one-fourth, with the amount of salt about the same a outside stream, or 4½ per cent; at 482 feet a vein of salt water reported, with an increased strength of one-third; at 708 feet 7 in a small amount of water was reached which was very strong offensive with gas, with a corresponding increase in strength of bri from 4½ to 9 per cent. A 10-inch square wooden conductor wa down to the bottom of the quicksand, a distance of 22 feet. B this a 1½-inch pipe was inserted (Schweitzer states that a 3-inch was inserted to a depth of 400 feet). The volume of water is cient for a 2½-inch pipe.

The log states that fresh water came in at 1,001 feet. Mr. I Cooper informed the writer that he was on the ground when the was sunk and that no fresh water was obtained. Others ma positive assertion that there was fresh water. This question ha important bearing on the possibility of a fresh-water supply in

A. BIG SALT SPRING, SALINE COUNTY.

B. SINKING CREEK, SHANNON COUNTY, ISSUING FROM UNDER NATURAL BRIDGE.

immediate vicinity, and it has already been discussed at Fayette, where the problem of city water supply is serious and where the advisability of sinking the present deep well down to the supposed fresh-water supply found in the Boonslick well has been considered. The following is an analysis of the water from this well, made by Woodward, probably in 1891, and published in Schweitzer's report on the mineral waters of Missouri.[a]

Analysis of water from Marshall well, Boonslick, Howard County.[b]

	Parts per million.		Parts per million.
Silica (SiO_2)	18	Sulphate radicle (SO_4)	1,392
Calcium (Ca)	967	Chlorine (Cl)	12,071
Magnesium (Mg)	413		21,441
Sodium (Na)	6,580		

While this is only a partial analysis of this spring, it indicates some very important conclusions. The saline springs of Saline, Howard, and Ralls counties have, it is believed, a deep-seated origin, and the deep wells at Sweet Springs, Malta Bend, Spalding, Boonslick, and Fayette are either adjoining or near salt-spring marshes. The wells at Spalding, Boonslick, and Fayette are located on such marshes. The Big Salt Spring (Pl. VI, *A*), one of a group of brine springs between the deep wells at Malta Bend and Sweet Springs, has been described by the writer as follows:[c]

The surface rock is near the base of the Mississippian, and the spring proper is an oval pool about 25 feet in diameter. The water boils up all over the surface of this pool, and is impregnated with sulphur. Its source is undoubtedly at a great depth.

After a brief discussion of the fluctuations of these springs in temperature and of the varying amounts of sulphureted hydrogen, as revealed by examinations made at different times, the writer continues:[d]

This central section seems to be a basin which receives the flow from the Ozarks from the southeast, being apparently inclosed on the south by the Sedalia fold and probably on the west by smaller folds which have not yet been fully outlined. If this view can be fully verified it might account for the concentration of salines in these waters. The presence of a considerable amount of calcium chloride in all the deep wells and brine springs of this district would presuppose the theory that this was a basin early shut off from the sea, in which the original sea water became concentrated.

The view quoted above has been more fully substantiated by the studies of the past few months.

Section 8 (Pl. V, p. 36) shows the structure, from west to east, of the Fayette basin in Howard County and of a part of the Sweet

[a] Missouri Geol. Survey, vol. 3, 1892, p. 71.

[b] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

[c] Shepard, E. M., Water-Sup. and Irr. Paper No. 114, U. S. Geol. Survey, 1905, p. 213.

[d] Op. cit., p. 214.

Springs basin in Saline County. To the south the horizons rise rapidly toward the Ozark Island, and to the north shallow well sections extending through the Pennsylvanian show a rise of the Mississippian floor in that direction, thus outlining the two well-defined basins just mentioned. These basins were probably developed early in the geologic history of the region, possibly at the close of the Cambrian, the flexures which had a northeast-southwest trend being more or less parallel with the old coast line of the Ozark Island and developing lines of weakness which were accentuated by further uplifts. The presence of these folds is indicated by deflections of Missouri River, as has previously been described (p. 36). The Ozark Island has probably been divided at times, and water connection between the great east and west seas has existed along what is now the line of Missouri River. Subsequent elevations of these anticlines to the north shut off these basins and left therein the fossil brines of ancient oceans, in which the present deposits were afterwards laid down.

The analyses of the water from the Boonslick spring and the Boonslick deep well, which are about 400 feet apart, show a striking similarity. The two are given below for convenience of comparison:

Analyses of water from Boonslick well and Boonslick spring. [a]

[Parts per million.]

	Well.	Spring.
Calcium (Ca)	968	1,105
Magnesium (Mg)	418	.....
Sodium (Na)	6,590	6,077
Sulphate radicle (SO_4)	1,391	1,440
Chlorine (Cl)	12,040	10,238
	21,407	18,860

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

The similarity of these two waters is striking. The log of the Boonslick well gives a record of the varying amounts of saline water found at different depths, and not until 708 feet was reached was water found having a composition similar to that which comes to the surface in the adjoining spring, a fact which seems in this case to demonstrate the deep-seated origin of the water. Moreover, the valleys where these brine springs occur are flat and seem to have been filled, to some degree, by deposits from the springs.

The Boonslick spring rises from a slightly elevated platform of muck. The water is highly charged with sulphureted hydrogen. The mound which the spring has apparently built up around itself is stained a beautiful purplish-red, the material consisting of clay, algæ, and slime. The purplish algæ seem to be covered in places by a dark

slaty-colored sediment. Mr. J. N. Newman, who resides in the vicinity, states that in the winter the flow from the spring is much greater, the water boiling up to the height of 1 foot.

FAYETTE.

One hundred yards south of the Missouri, Kansas and Texas Railway station at Fayette is a well owned by the Fayette Mineral Well Company. Depth, 860 feet; altitude above tide, 655 feet; diameter of casing, 4 inches; temperature of water, 61.5° F.; of air, 78° F.; surface formation, Des Moines. This well was sunk for the purpose of obtaining a supply of water for the city, but at a depth of 860 feet so strong a flow of salt water was encountered that the original idea was abandoned. The well is in close proximity to the Fayette salt springs, at the head of a small salt branch. The area occupied by these springs is about 50 feet in diameter. The Howard and Saline County basins are both characterized by numerous irregular salt marshes and springs of the same character.

The following log and analysis of the water of the Fayette well have been furnished by Prof. E. E. Wildman, of Fayette College. The log was made from samples of drillings preserved by the late J. W. Kilpatrick, formerly professor of geology in that institution:

Log of well of Fayette Mineral Well Company, Fayette, Howard County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (135 feet):		
Loess and sandstone	25	25
Clay	12	37
Slate and gravel	34	71
"Soapstone" (?)	19	90
Blue clay	10	100
"Soapstone" (?)	35	135
Des Moines (464 feet):		
Flint and limestone	80	215
Gray flint, soft limestone, and coal	25	240
Salt and sandstone	35	275
White and brown limestone	225	500
Salt and sandstone	22	522
Sandstone with sulphur	49	571
Blue limestone	14	585
White and gray sandstone	14	599
Mississippian (Keokuk-Burlington) (271 feet):		
Lime and sandstone	146	745
White sandstone	10	755
Lime and sandstone	75	830
Brown flint and sandstone	20	850
Iron and sandstone	6	856
Gray sandstone	14	870

The great thickness of the Des Moines, which fills the Howard basin, as shown in section 8 (Pl. V, p. 36), is to be noted in this log.

Analysis of water from Fayette mineral well.[a]

[Analyst, Kennicott Water Softener Company, Chicago, Ill.]

	Parts per million.		Parts per million.
Silica (SiO_2)	20	Sodium (Na)	8,197
Iron and aluminum oxides ($Fe_2O_3 + Al_2O_3$)	14	Bicarbonate radicle (HCO_3)	166
Calcium (Ca)	1,042	Sulphate radicle (SO_4)	1,343
Magnesium (Mg)	340	Chlorine (Cl)	14,440
		Suspended matter	128
			25,670

The suspended matter is, to a considerable extent, sulphur. The analyst did not give the sulphur or the sulphureted hydrogen. The water has a feeble flow and contains a considerable amount of the gas. From this analysis it is seen that the water resembles a fossil brine from an ocean basin that has never been leached out since the area was originally shut off from the sea.

At present the water from this spring is used for medicinal purposes. A small bath house, with hot and cold water, and a swimming pool 30 by 64 feet adjoin the well. The water is recommended for rheumatism and skin and blood troubles.

JACKSON COUNTY.

KANSAS CITY.

Dr. G. C. Broadhead gives the log of a well at Kansas City, Jackson County, located not far from the union station:

Log of well at Kansas City, Jackson County.

	Thickness.		Depth.	
	Ft.	in.	Ft.	in.
Pleistocene (37 feet):				
Loess from surface to bed rock	37	0	37	0
Des Moines (708 feet):				
Fine-grained bluish limestone	21	0	58	0
Light-blue clay	3	0	61	0
Dark colored clay	4	0	65	0
Gray limestone	13	0	78	0
Dove-colored clay shale	100	0	178	0
Bituminous sand clay; bitumen rose to surface	4	0	182	0
Clay	81	0	263	0
Bituminous limestone, brown	4	0	267	0
"Soapstone"	5	0	272	0
Limestone; increase of water	18	0	290	0
Arenaceous clay and soft drab sandstone	4	0	294	0
Light-buff limestone	13	0	307	0
Dove-colored "soapstone"	24	0	331	0
Dove-colored argillaceous clay	23	0	354	0
Dark clay; shales, shelly coal, fossils	5	0	359	0
Dark blue micaceous clay	25	0	384	0
Dark-blue fine-grained sandstone	37	0	421	0
Dark shales; salt water	4	0	425	0
Coal	0	4	425	4
Fire-clay	10	0	435	4
Clay and limestone; marble	5	8	441	0
Dark "slate" and coal; fossil plants; salt (flowing)	1	0	442	0
Coal; dense and bright	0	6	442	6
Clay and limestone	16	0	458	6
Coarse gray sandstone; strong brine	12	0	470	6
Gray fine sandstone	10	6	481	0
Blue clay	5	0	486	0
Clay or "soapstone"	7	0	493	0
Dark, drab-colored fine-grained sandy clay	119	0	612	0
Black shale	3	0	615	0

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to grams and parts per million at United States Geological Survey.

Log of well at Kansas City, Jackson County—Continued.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Des Moines—Continued.				
Coal	1	0	623	0
Clay, with sand	50	0	673	0
Thin laminated dark clay with shales	6	0	679	0
Black bituminous shales	3	0	682	0
Coal	1	8	683	8
Clay and mud	16	4	700	0
Mud	34	10	734	10
Dark, mottled crystalline sandstone	10	2	745	0
Mississippian (13+ feet):				
Vitreous crystalline limestone	13	0	758	0

The log of a deep well in Jackson County was furnished by Messrs. M. L. Fuller and S. Sanford. It is believed to be the record of a well recently sunk in Kansas City, though the specific location was not given.

Log of well in Jackson County.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Earth	14	6	.....	
Yellow shale	2	0	16	6
Fire clay	35	0	51	6
Limestone, hard	9	0	60	6
Fire clay, light to dark	7	0	67	6
Brown umber, good	4	6	72	0
Sandy limestone, hard	2	0	74	0
Limestone, hard	36	0	110	0
"Soapstone"	6	0	116	0
Limestone, very hard	8	0	124	0
Fire clay, dark, shaly	1	0	125	0
Limestone	6	0	131	0
Fire clay, dark	6	6	137	6
Limestone	8	6	146	0
Shale	11	0	157	0
Sandstone	4	0	161	0
Black slate; salt water	0	6	161	6
Coal, first seam	1	6	163	0
Fire clay	2	0	165	0
Limestone	3	0	168	0
"Soapstone"	17	0	185	0
Sandy shale	1	0	186	0
Black slate (iron pyrites with gas, pressure 125 to 150 pounds)	1	0	187	0
Coal, second seam	4	0	191	0
Fire clay	5	0	196	0
Sandy shale	1	0	197	0
Fire clay	4	9	201	9
"Slate," black	1	3	203	0
Fire clay, light to dark	66	6	269	6
Sandy shale, hard	1	0	270	6
Black shale and "soapstone"	2	0	272	6
Fire clay	33	0	305	6
Black "slate"	0	6	306	0
Coal, third seam	1	0	307	0
Sandstone, with partings of clay	7	0	314	0
Fire clay	7	0	321	0
"Rock"	5	0	326	0
Fire clay	2	0	328	0
"Soapstone," soft, blue	20	6	348	6
Coal, fourth seam	0	6	349	0
Fire clay	16	6	365	6
Coal, fifth seam	0	2	365	8
Fire clay	29	4	395	0
"Soapstone"	4	0	399	0
Fire clay	14	0	413	0
"Soapstone," dark	7	0	420	0
Sandstone, soft, free	11	0	431	0
Kaolin, sandy	10	0	441	0
Sandy shale	4	0	445	6
Fire clay, shaly	7	6	452	0
Sandstone	17	0	469	0
Fire clay, dark	30	6	500	0
Shale, sandy	4	0	504	0
Fire clay	4	0	508	0
Shale, sandy crevice; strong brine in crevice, filled well within 100 feet of top	2	0	510	0

The above formations are all in the Des Moines group.

Record of diamond-drill well 10 miles northeast of Kansas City, Mo.

[Elevation of well mouth, 925 feet. Correlations by E. O. Ulrich.]

	Thickness.	Depth.
	Feet.	*Feet.*
Lower Coal Measures	750	750
Boone limestone (?):		
Limestone, shelly in places, with shale partings	75	825
Light-colored limestone, flinty layers	260	1,085
Dark limestone, with shelly layers	100	1,185
Dark reddish sand	15	1,200
Joachim (?): Bluish, fine-grained limestone, shelly in places	57	1,257
St. Peter: Sandstone, white at top, reddish at bottom	64	1,321
Cambro-Ordovician:		
Gray and brown limestone	129	1,450
Shelly and clayey limestone	10	1,460
Light, coarse, porous limestone	160	1,620
Shelly limestone	20	1,640
White sandstone	16	1,656
Flinty, light, porous limestone; water disappeared or was lost	74	1,730
Gray clayey and sandy limestone	20	1,750
Hard, gray, fine-grained limestone	70	1,820
Hard, gray, fine-grained sandstone	15	1,835
Gritty, porous, crystalline limestone, in places white and flinty	215	2,050
Hard, coarse sandstone	50	2,100
Cambrian:		
Limestone, with seams of gray and brown shale	40	2,140
Dark and light fine-grained limestone	110	2,250
Hard, coarse sandstone	98	2,348
Granite	53	2,401

JOHNSON COUNTY.

LEETON.

One-half mile southwest of Leeton, Johnson County, is a well owned by the Chicago, Rock Island and Pacific Railway and drilled by George Austin and W. E. Carner. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Chicago, Rock Island and Pacific Railway well near Leeton, Johnson County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	14	14
Limestone, very hard	18	32
Shale, medium	50	82
Coal, bituminous	2	84
Shale, medium	6	90
Coal	1	91
Shale; small flow of gas	623	714
Limestone, hard	500	1,214

LAFAYETTE COUNTY.

HIGGINSVILLE.

At Higginsville, Lafayette County, the Higginsville Prospecting Company in 1898 drilled a well near the Missouri Pacific Railway station to a depth of 1,512 feet. This well has a diameter of 10 inches at the top and 4½ inches at the bottom; it is cased all the way down.

The principal source of water is in sandstone, apparently the Kinderhook, at a depth of 656 feet; another strong flow was obtained at a depth of 1,350 feet in a sandstone that was probably the Roubidoux. A strong flow of salt water was struck at a depth of 1,070 feet in the St. Peter sandstone. The water rises within 80 feet of the surface, the supply seeming to be unlimited. The president of the company, Mr. J. H. Burgan, to whom the writer is indebted for this information, states that pumping 100,000 gallons per day for a week made no change in the level of the water. Salt water, charged with sulphureted hydrogen, now comes in through the casing and the well is not used. Mr. Burgan furnished the following log:

Log of well at Higginsville, Lafayette County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (68 feet):		
Earth and clay	68	68
Des Moines (332 feet):		
Sandstone	112	180
Asphaltic sand	8	188
Slate	5	193
Soapstone	157	350
Sandstone	20	370
Keokuk (87 feet):		
Gray limestone	67	437
White limestone	13	450
Asphalt and quartz rock	7	457
Burlington (63 feet):		
Coarser limestone	38	495
Dark limestone	5	500
Hard gray limestone	20	520
Kinderhook (195 feet):		
Brown limestone	36	556
Dark-brown limestone	100	656
Sandstone; heavy flow fresh water	35	691
Hard limestone	24	715
Devonian (55 feet):		
Hard white limestone	27	742
White sand; water	20	762
Darker brown sand	8	770
"Trenton" and Joachim limestone (281 feet):		
Limestone	201	971
Trenton rock, close grained; trace of oil	45	1,016
Trenton rock, hard; slight trace of oil	35	1,051
St. Peter sandstone (150 feet):		
Soft sandstone	20	1,071
St. Peter sandstone; salt water	130	1,201
Jefferson City limestone (145 feet):		
Limestone; salt water	145	1,346
Roubidoux sandstone (167 feet):		
Sandstone; fresh water	25	1,371
Very hard white limestone	142	1,513

A number of drill holes ranging from 80 to 250 feet in depth are noted in Marbut's report on the geology of the Lexington sheet, Lafayette County.[a]

[a] Marbut, C. F., Missouri Geol. Survey, vol. 12, pt. 2, 1898, pp. 196-247.

MACON COUNTY.

LA PLATA.

At La Plata, Macon County, the La Plata Electric Light Company drilled a well 435 feet deep one-eighth of a mile northeast of the town. The work was done by Durand, of Iola, Kans. La Plata is situated on the crest of the divide between Missouri and Mississippi rivers, at an altitude of 914 feet. The well has an 8-inch bore and was completed in 1902. The principal flow is from sandstone, at a depth of 140 feet, and the water rises within 90 feet of the surface. Another water-bearing sandstone was found at 430 feet. The supply is only about 3 gallons per minute and a little pumping soon lessens that amount. By hard pumping the well can be entirely drained. The water is used for boiler purposes.

The following analysis, neither date nor name of analyst being given, is furnished by the company:

Analysis of water from electric-light company's well, La Plata. Macon County.[a]

	Parts per million.		Parts per million.
Silica (SiO^2)	3.4	Carbonate radicle (CO_3)	283
Iron and alumina oxides ($Fe_2O_3+Al_2O_3$)	13	Sulphate radicle (SO_4)	195
Calcium (Ca)	109	Chlorine (Cl)	11
Magnesium (Mg)	38		698.4
Sodium (Na)	96		

MACON.

The following notes on the record of the deep well drilled by the mining company of Macon in the summer of 1887, which furnishes a key to the geology of this immediate vicinity, are taken from the account by W J McGee:[b]

The boring in Macon.—The prospect bore is located in the southeastern part of the city, in a ravine some 30 feet deep, where the drift was found to be 36 feet in thickness. An ordinary plunge drill was used. The diameter of the bore is 13 inches in the drift and 8 inches in the rock to 320 feet from the surface, where a strong flow of water was encountered and the diameter was reduced to 5 inches. Samples were taken by means of the "sand pump" at frequent intervals, particularly when change in character of material was indicated by the behavior of the drill; and special care was exercised in taking samples and in determining thickness of strata when borings indicated the proximity of coal seams. The samples were collected and preserved by the well driller and one or more representatives of the citizens' committee acting in conjunction with him; and the depth from which each was taken was indicated upon the box in which it was preserved. In the following notes the depths are transcribed from this record. The specimens were personally examined; and the notes represent the inferences then made as to the character of the strata from which specimens were derived rather than accurate descriptions of the specimens themselves.

[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

[b] Trans. St. Louis Acad. Sci., vol. 5, 1888, pp. 326-333.

Log of the deep well at Macon, Macon County.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
1. Drift (no specimens preserved)	36	0	36	0
2. Blue calcareous-argillaceous shale breaking down into clay with a few firm fragments	9	0	45	0
3. Hard, brittle blue limestone with conchoidal fracture, mixed with shaly débris and mud evidently derived from the breaking up of shale	1	0	46	0
4. Black shale breaking up into graphite-like mud	2	0	48	0
5. Coal, with a few fragments of shale	1	1	49	1
6. Blue shale or clay containing a little grit, breaking down into mud, with a few shaly scales	5	11	55	0
7. Tenacious blue clay with a few shaly flakes and a trace of grit	10	0	65	0
8. Gray calcareous shale with a few fragments of limestone, of which some are veined with calcite and exhibit conchoidal fracture	5	0	70	0
9. Black shale, the larger fragments of which exhibit parallel lamination	3	2½	73	2½
10. Coal	1	9½	75	0
11. Tenacious blue clay containing a little gritty matter	33	8	108	8
12. Black graphite-like clay with a few bits of gray clay, the whole containing a little gritty matter and scales of shale	17	4	126	0
13. Dark-gray or black clay evidently derived from slightly calcareous shale containing fragments of dark-blue limestone	0	6	126	6
14. Firm black carbonaceous shale	1	9	128	3
15. Slightly calcareous gray clay, with abundant shaly scales	8	3	136	6
16. Calcareous gray clay, with shaly scales	18	6	155	0
17. Slightly calcareous dark-gray shale	30	0	185	0
18. Light-gray limestone, pure, probably massive or thick bedded, with conchoidal fracture	28	0	213	0
19. Light-gray subcrystalline limestone, intermixed with dark-gray shale	7	0	220	0
20. Light-gray, slightly calcareous shale and clay	53	0	273	0
21. Dark-gray, slightly calcareous clay	3	0	276	0
22. Calcareous gray shale	5	6	281	6
23. Light-gray cherty limestone	5	0	286	6
24. Light-gray limestone, dark-gray calcareous shale, and chert	3	6	290	0
25. Light-gray cherty limestone	30	0	320	0
26. Blue-gray calcareous shale	5	0	325	0
27. Light cherty limestone and dark-gray calcareous shale	10	6	335	6
28. Light-gray and dark nodular calcareous shale	39	6	375	0
29. Light-gray siliceous limestone and chert	21	0	396	0
30. Light-buff pulverulent rock containing beautiful crystals of carbonate of lime and carbonate of iron, and leaving a considerable residue (probably siliceous and magnesian) after digestion in acid	14	0	410	0
31. Dark-gray arenaceous shale, light-gray calcareous shale, and crystals of calcite	72	0	482	0
32. Light-gray arenaceous and calcareous shale with light-buff powder like that at 410 feet	27	0	509	0
33. Blue sparry limestone with fossil markings	23	0	532	0
34. Shaly blue limestone	43	0	575	0
35. Light-gray and dark-blue shaly limestone	60	0	635	0
36. Blue limestone	17	0	652	0
37. Light-blue sparry limestone	112	0	764	0
38. Light-blue cherty and arenaceous limestone	36	0	800	0
39. Gray sparry limestone and fine fissile blue shale	95	0	895	0
40. Massive blue shale or indurated clay	100	0	995	0
41. Fine calcareous sand	5	0	1,000	0

The following summary of this log is in part taken from a table given by McGee, who compared the materials and thickness of the several strata penetrated with the general sections developed by the State surveys of Missouri, Illinois, and Iowa (a sort of composite of which was prepared for use in prognosticating the results of the boring):

Summary of log of well at Macon, Macon County.

System.	Formation.	Petrographic character.	Numbers in McGee's log.	Thickness.
				Feet.
Carboniferous	Lower Pennsylvanian	Shales, clay beds, limestones, coal seams	2–17	215
	St. Louis	Limestone	18–19	35
	Keokuk	Somewhat calcareous shales	20–22	62
	Burlington	Nodular calcareous shales	28	40
		Siliceous limestones, calcareous shales	29–33	157
	Kinderhook	Shaly, nonsiliceous limestones	34–37	232
Devonian	Hamilton [a]			
Silurian	Niagara	Cherty limestone, passing into shale	38–39	131
	Hudson	Shales or indurated clays	40	100
		Sandstone	41	
	Trenton [b]			[c] 450
	St. Peter [b]			[c] 50
				1,026

[a] Not recognized. [b] Not reached. [c] Estimated.

D. B. Moore, of Macon, has sunk a number of wells ranging from 125 to 210 feet in depth, and has preserved a careful record of them. He states that most of the wells driven to a depth of 150 to 200 feet are dry, and that most of the water used in that vicinity is from the drift. George Kohl sunk a well one-half mile west of Macon to a depth of 60 feet in drift, and it was perfectly dry. At a distance of 75 feet a well 20 feet deep struck water that rose within 8 feet of the surface. On the Pohlman's farm, 7 miles southeast of Macon, a well drilled 209 feet deep failed to get water.

Four miles southeast of Macon is a well owned by S. T. Brock and drilled by S. D. Harris. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Brock well near Macon, Macon County.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil	4	4
Joint clay	16	20
Sand, with a small vein of water	2	22
Red clay	18	40
Sand and water	3	43
Red clay	37	80
Blue clay	15	95
Fine sand, blue, with water all through the sand	20	115

The water rises within 20 feet of the surface and has been pumped for two years. The beds all belong to the Des Moines group.

Four miles northwest of Macon is a well owned by T. E. Wardell and drilled by S. D. Harris. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Wardell well near Macon, Macon County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (54 feet):		
Surface rock, soil to joint clay	54	54
Des Moines (110 feet):		
Gray sandstone	40	94
Soft shale, gray; small vein of water rises 20 feet	66	160
Hard slate	1	161
Coal	3	164
Mississippian (136 feet):		
Blue lime rock	26	190
White lime rock, very hard	70	260
Lime rock which was very hard to drill; struck water in seam of rock at 290 feet; water rises within 90 feet of surface	40	300

MILLER COUNTY.

OLEAN.

There are several wells in and around Olean, Miller County, on Blythes Fork. One, owned by the Olean Canning Company, in sec. 12, T. 42, R. 15, at an altitude of 746 feet above tide, is 56 feet deep. Flowing water was found at the bottom. The well was drilled in 1893 and no change in the flow has ever been noted. The water is softer than that in the shallow dug wells of the vicinity and is used for the boiler at the canning factory. The drill passed through 10 feet of soil and creek gravel and 40 feet of broken flint and sandstone. In order to make the water flow into the casing, the pipe is inclosed in a bag of flaxseed which was lowered beyond the gravel layer. The seeds swell and cut off the escape of water through the river gravel. The cost of the well was $50.

Another well is located near the flouring mill of Joseph Guttermeier, in sec. 1, T. 42, R. 15. It was drilled in 1893 with a 7-inch bore to a depth of 85 feet. The flow of water, about 110 gallons per hour, does not vary ordinarily, but it may be decreased by pumping. At a depth of 50 feet water was struck that rose within 4 feet of the surface; at a depth of 85 feet it flowed. The water is soft, with a slight odor of sulphur. It is used for drinking and for the boiler at the flouring mill. The altitude of the curb is 764 feet. The cost of drilling was 75 cents per foot, or $64 for the entire work. The following is the log of the well:

Log of Guttermeier well near Olean, Miller County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and gravel	4	4
Limestone and flint	78	82
Shale	2	84
Sandstone	1	85

On his place near the railway station at Olean Mr. J. C. Johnston drilled a well, with a 6-inch bore, to a depth of 67½ feet. The water rose to the surface from the bottom of the well and flows 7½ gallons per minute. It is soft and is used for household purposes. The drill passed through 10 feet of soil and 57½ feet of chert and sandstone.

A second well, at an altitude of 754 feet above tide, was sunk in a farmyard adjoining the one just described. This well is the lowest in the group, and when allowed to flow full head it will, in a short time, cause all the others to stop flowing, except the one at the flouring mill one-half mile north of Olean. The water is soft. The well cost $80.

Another well, located at the Franklin, Lux & Proctor livery stable, was drilled in 1901, with a 6-inch bore, to a depth of 50 feet. At the depth of 25 feet the water rose to the surface. It is moderately soft and is used in the livery stable. The well cost $50. The wells at the livery stable and store have ceased to flow, owing probably to leakage in the pipe and to the sinking of neighboring wells at lower levels.

The general dip of the sandstone strata overlain by impervious shale in this region gives rise to conditions favorable to artesian flow; but it is probable that a flow could be obtained at no point in this vicinity having an altitude of over 775 feet above tide. All the Miller County wells probably obtain water from either the Roubidoux formation or the Gasconade limestone.

Ball and Smith[a] state that—

> One of the drill holes at the Son prospect, in sec. 19, T. 41, R. 15 W., is a flowing well. This is situated near the top of the Gasconade limestone and is 12 feet above the bottom of Little Gravois Creek. The hole is 140 feet deep, no water having been struck up to 100 feet. * * * In the bottom of Baileys Branch, 2½ miles northwest of Iberia, George Graves obtained a flowing well at 60 feet, in the Gasconade limestone.

MONITEAU COUNTY.

CALIFORNIA.[b]

About 7 miles east of California, in sec. 17, T. 45, R. 14, on the south side of the road leading to that town, is a well owned by Karl Messerli. It is in a valley somewhat lower than the town. The well was completed May 8, 1902, and is 265 feet deep, with a 5⅞-inch bore. The strongest flow was obtained at 90 feet and had its source in limestone and flint. Two water-bearing beds were found, at 30 and 60 feet.

[a] Ball, S. H., and Smith, A. F., Geology of Miller County: Missouri Bureau Geology and Mines, 2d ser., vol. 1, 1903, p. 196.

[b] For data regarding these wells the writer is indebted to Mr. E. B. Fulkes, of the Missouri Botanical Garden, St. Louis, who drilled them.

The water is clear, cold, and hard. This well is about 200 yards east of a dwelling house and cheese factory, both of which are supplied with water from a running spring. The well lessened the flow of the spring, but did not stop it. The following log of the well was obtained:

Log of Messerli well, near California, Moniteau County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	3	3
Flint bowlders	22	25
Limestone	113	138
Hard sandstone	8	146
Limestone	119	265

This well obtains water from the Jefferson City limestone. Another, on the same farm, about 1,000 feet farther west, near a small stream, was drilled in 1902 to a depth of 182 feet, with a 5⅞-inch bore. Water was struck first in limestone, at a depth of 40 feet. When the well reached 65 feet the water ran over the top of the pipe in a small stream, the force increasing to a depth of 105 feet, when the flow became strong enough to raise the full column of water to a height of 3 feet. The water is clear, cold, and hard. This well stopped the flow of the other well and of the cheese-factory spring. Later, a cap was placed on the top of the casing and the other well and spring again became active.

The Crown Mining Company, of California, drilled a well 1½ miles east of town, on the north side of the road, in the N.½ SE. ¼ sec. 23, T. 45, R. 15, in a valley which is considerably lower than the courthouse. This well was drilled to a depth of 175 feet, with a 5⅞-inch bore, and completed in August, 1902. The water rises within 6 feet of the surface. It is clear, cold, hard, and charged with sulphureted hydrogen. The following log was obtained:

Log of Crown Mining Company well, near California, Moniteau County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and gravel	9	9
Limestone	41	50
Bowlders, blue clay, and iron pyrites	25	75
Limestone, flint bowlders, and some zinc at 80 feet	30	105
Solid limestone	35	140
Bowlders, limestone, flint, blue clay, and slate	14	154
Limestone	21	175

Flowing wells are also found in sec. 1, T. 43, R. 17; sec. 6, T. 44, R. 17, and sec. 10, T. 44, R. 14. All these wells obtain water from the Jefferson City limestone, and their artesian source is on the western slopes of the Ozarks.

MORGAN COUNTY.

FORTUNA DISTRICT.

In Morgan County and near Fortuna, Moniteau County, in T. 44, R. 17, according to the statement of Mr. E. A. Pettibone, there are about 20 flowing wells. These were all prospect holes sunk by lead and zinc mining companies. The water is obtained from flint beds at the base of the Burlington limestone. None of these wells are utilized, but they demonstrate the existence of another interesting artesian district. Their catchment area is to the southeast, and the rocks of

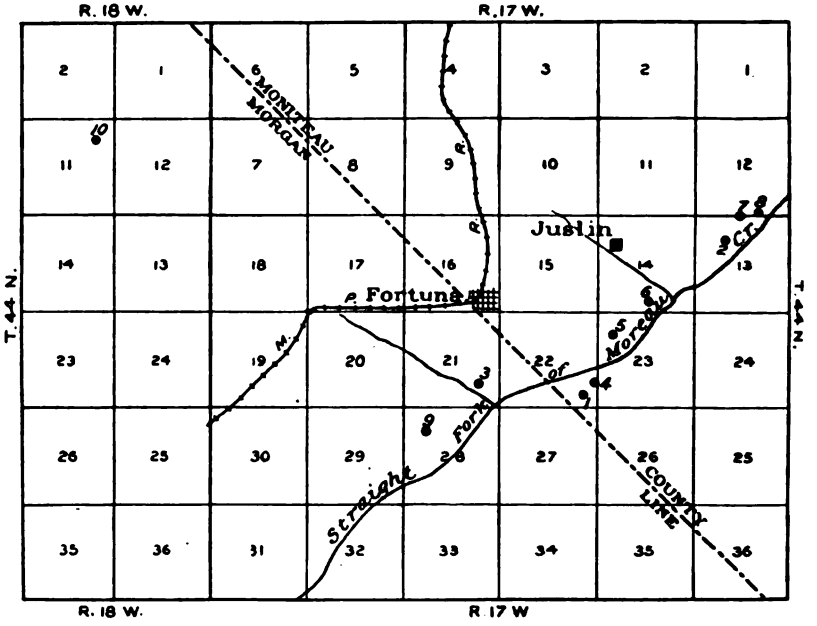


FIG. 3.—Group of artesian wells on Straight Fork of Moreau Creek, near Fortuna.

this region dip to the northwest along the western slope of the Ozark dome. The wells all lie along the valley of Straight Fork of Moreau Creek and may be located by means of the accompanying sketch map (fig. 3).

No. 1, the Singer well, and No. 2, on the Hutchinson tract, are 200 feet deep. The water was struck at a depth of about 140 feet, and the flow is strong. No. 3 is a group of three wells on the Capellar & Osier tract, each 200 feet deep, with a flow of water rising from a depth of 133 feet. No. 4 is a group of four wells on the Woodyard and Parkersburg Lead and Zinc Company's tract, all 200 feet deep, with water reached at about 40 feet. No. 5 is a group of four wells on the Missouri Lead and Zinc Mining Company's tract, each 200 feet deep, with a flow struck at 100 feet. No. 6 is a well on the Dug Hayes property.

200 feet deep, with flowing water reached at 40 feet. No. 7 is a well on the Newkirk tract, 200 feet deep, with flowing water reached between 156 and 160 feet. No. 8 is a well on the Dug Hayes tract No. 2, 200 feet deep, with flowing water at 120 feet. No. 9 is a well 100 feet deep, sunk by Milton McDaniel about 15 feet above the bed of a little draw and 40 feet above the middle branch of Moreau River. This is the farthest well to the south and has a barometric altitude of 869 feet, the altitude of Fortuna being 959 feet. The water in all these wells is clear, cold, and hard, typical of the Burlington limestone. The temperature of those tested is 59° F., with an air temperature of about 80° F.

Near Fortuna is a well owned by the Mary M. Mining Company and drilled by Charles E. Miller. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of well of Mary M. Mining Company, near Fortuna, Moniteau County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and clay	10	10
Rock	15	25
Limestone	25	50
Magnesia limestone	10	60
Magnesia limestone and mundic	10	70
Limestone, pink spar, and mundic	10	80
Limestone and flint	10	90
Limestone and flint, jack shines	10	100
Limestone, pink spar, jack shines	10	110
Limestone, black flint, very good jack and lead	11	121
Limestone, black flint, very good jack and betts	14	135
Limestone, white flint, small shines	15	150
Limestone, black flint, jack shines	10	160
All pink spar	6	166
Pink spar and black flint	15	181
Limestone and pink spar	5	186
Limestone, jack shines	5	191
Limestone and flint, jack prospect	20	211

This well is probably all in the Jefferson City limestone.

BLUFF SPRING AND GLENSTEAD.

Mr. J. F. Todd states that there is a strong flowing well in an old prospect hole in the NE ¼, sec. 11, T. 44, R. 18, in Morgan County, within a quarter of a mile of the Bluff Spring mines; also another a mile east and a quarter of a mile north of Glenstead, Morgan County, in sec. 6, T. 43, R. 17. Neither of these two wells was visited.

PETTIS COUNTY.

HUGHESVILLE.

Two miles northwest of Hughesville, Pettis County, is a well owned by Raymond Voigt and drilled by J. B. Ellison. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Voigt well, near Hughesville, Pettis County.

	Thickness.	Depth.
	Feet.	*Feet.*
Yellow clay, stiff	30	30
Blue clay, mud and sand mixed, stiff and waxy	170	200
Very hard cotton rock, gray	53	253

PETTIS.

At Pettis, Pettis County, is a well owned by Elijah Hatsenpiller and drilled by G. W. Yeager. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of the Hatsenpiller well, Pettis, Pettis County.

	Thickness.	Depth.
	Feet.	*Feet*
Soil	20	20
Clay	20	40
Bowlders and clay	78	118
Hard blue limestone, some gray	97	215
Blue clay, gravel, sand, flint rock, and particles of iron	15	230
"Cotton" rock, black sand	2	232

SEDALIA.

The former Sedalia water supply from Flat Creek having proved insufficient in time of drought, the Sedalia Water and Light Company drilled a deep well about 1 mile southeast of Forest Park in the valley of Flat Creek, 3 miles south of the city. Five other wells have been

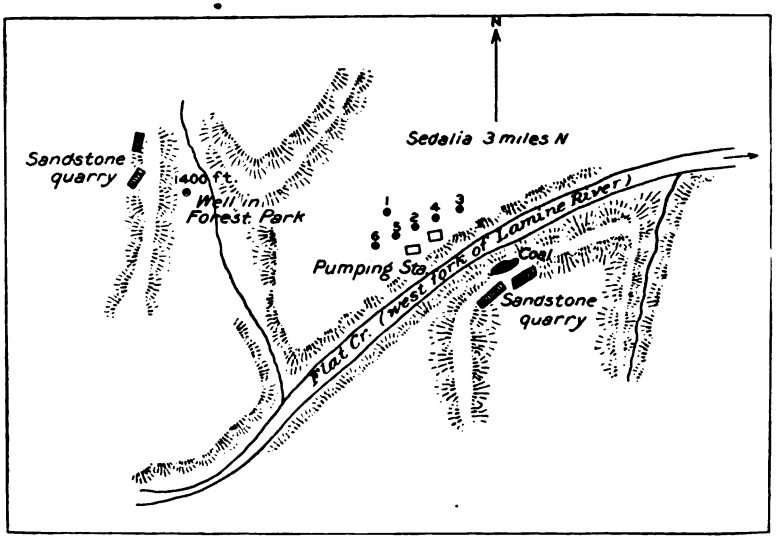


FIG. 4.—Diagram of the Sedalia waterworks wells.

sunk, as indicated in fig. 4. Well No. 1 was drilled to a depth of 670 feet. At 620 feet a gray sandy flint 12 feet thick was struck, then a softer gray sandy rock, with an intercalated bed of soft blue clay 8 feet thick. Under this was found a harder dark sandy formation in which drilling was stopped because of bad ground and the fear that the jars might get fast. Well No. 2, completed in 1901, is at an elevation of about 800 feet above tide. The diameter of the casing is 8

inches. The surface formation is Burlington limestone. The log of the well and other information concerning it have been furnished by Mr. L. P. Andrews, president of the water and light company.

Log of well No. 2 of Sedalia Water and Light Company, Sedalia, Pettis County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (25 feet):		
Soil	15	15
Sand and gravel	10	25
Mississippian (201 feet: Burlington 52 feet, Kinderhook 149 feet):		
Limestone (cotton rock)	27	52
Limestone and flint	20	72
Hard flint	5	77
Limestone and flint	87	164
Gray limestone	24	188
Sandy limestone	13	201
Cotton rock	25	226
Devonian (23 feet):		
Limestone and flint	23	249
Joachim limestone (40 feet):		
Hard flint	17	266
Limestone	23	289
St. Peter sandstone (71 feet):		
White sand rock	71	360
Jefferson City limestone (151 feet):		
Limestone	25	385
Limestone and flint	22	407
White limestone	50	457
Limestone and flint	54	511

The correlations in this log have been made by a comparison of the record of this well with those of well No. 1, 670 feet deep, and of the Forest Park well, 1,612 feet deep. The Jefferson City limestone extends to a depth of 620 feet, and is followed by 380 (?) feet of the Roubidoux and 612 feet of Cambrian or Archean. The driller who sunk the Forest Park well stated that he could not remember the whole log, but distinctly recalled the fact that the last 400 feet was in hard white sandstone.

The late Mr. R. A. Blair[a] gave the following section at Sedalia, and it checks remarkably well with the drill section:

Generalized section at Sedalia, Pettis County.

	Feet.
Burlington limestone	70
Chouteau (Kinderhook)	140
Devonian	30
Silurian (Cambrian)	75+

The water in well No. 2 rises 18 inches above the surface.

[a] The Sedalian, December, 1903, p. 20.

Analysis of water from deep well No. 2 at Sedalia. [a]

[Analysis by St. Louis Sampling Works, July 18, 1902.]

	Parts per million.		Parts per million.
Silica (SiO_2)	8.2	Chlorine (Cl)	2.7
Calcium (Ca)	62		294.7
Magnesium (Mg)	34	Residue on evaporation	316
Sodium (Na)	1.8	Residue on ignition	233
Carbonate radicle (CO_3)	164		
Sulphate radicle (SO_4)	22		

Water in shallow wells in Sedalia is too highly charged with lime and magnesia sulphates and carbonates to be good for either boiler or drinking purposes; but that city has now, with these inexhaustible deep wells, one of the best water supplies in the country. The main flow comes from the St. Peter sandstone, at a depth of 289 to 360 feet.

A deep well in Forest Park, about a mile north of the waterworks wells, was drilled in 1893. The following log was contributed by Mr. F. A. Sampson, of Columbia:

Log of deep well at Forest Park, near Sedalia, Pettis County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	30	30
Coarse sandy yellow limestone, with white chert	25	55
Gray shaly, earthy limestone, with some white chert and crinoid stems	55	110
Light-gray crystalline limestone, with some white chert	52	162
Fine-grained gray magnesian limestone	36	198
Darker-gray crystalline magnesian limestone, with bluish and white flint	62	260
Very fine white quartz sand	160	420
Grayish-white magnesian limestone; some shows oolitic structure with fine quartz grains and very little white flint	60	480
Fine white limestone and fine white quartz	35	515
Fine quartz sand, nearly pure	150	665
Whitish magnesian limestone, with some whitish flint	215	880
Whitish-gray magnesian limestone; resembles fine sand (may contain sand)	100	980
Fine white quartz sand	20	1,000
White and reddish crystalline limestone (marble)	150	1,150
Coarse white quartz sand	25	1,175
Fine-grained sand with a little flint	85	1,260
Olive-green shale and a little white calcite	40	1,300
Dark-gray magnesian limestone and white sandstone	95	1,395
Coarse sand, dark gray, with traces of a hornblende-like mineral	5	1,400
Olive and greenish-gray shale, with sand like preceding	15	1,415
Gray quartz sand, with greenish shale and fine grains resembling hornblende	15	1,430
Gray quartz sand, ferruginous	15	1,445
Fine quartz sand with mica; light quartz sand at 1,470 feet	25	1,470
Coarse round white sand; transparent, good glass sand	110	1,580
Fine reddish-white sand	32	1,612

This log differs somewhat from those of several of the waterworks wells, which check closely with each other. The large amount of sandstone shown in this record is difficult to account for. Several parties who saw the drillings state that the last 400 or 500 feet was

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

hard white sandstone. From the log, as given, the last 200 or 300 feet might be either the La Motte sandstone or, possibly, the Archean quartz or porphyry. This well is about 20 feet higher than the waterworks wells, and water rises within 6 feet of the surface. Correlations made from this record would vary somewhat from those of the waterworks wells.

The artesian pressure comes from the catchment basin in Morgan County, in the Ozarks. Section 3 (Pl. IV, p. 30) illustrates the artesian conditions in this vicinity.

SMITHTON.

On a farm near Smithton, Pettis County, in a stream bed in sec. 11, T. 45, R. 20, is a well owned by Dr. W. C. Page. It was drilled in 1901 to a depth of 146 feet, with a 6½-inch bore, and cased to a depth of 15 feet. Water was struck at the bottom in rock and rises to the surface. It is clear, cold, and soft, and has a mineral taste. No log was kept and no analysis has been made.

The description of another well in the immediate vicinity is given for the sake of the log. This well, which is not flowing because of its situation on a high plateau, is 4 miles west of Smithton, Pettis County, in sec. 7, T. 45, R. 20, on a farm owned by Mr. Gabbatt, of Sedalia. It was drilled to a depth of 215 feet, with a 6-inch bore, and cased 26 feet with a 6¼-inch casing. Water was found at 175+ feet in sand and at 198 feet in gravel. The water is reasonably soft. It rises within 140 feet of the surface. It is raised by a pump worked by a gasoline engine which cost $300. The water is used for stock and drinking purposes. The well was drilled by W. C. Ellison, of Smithton, at a cost of $150. The water of this well probably has its source in Devonian rock.

Log of Gabbatt well, near Smithton, Pettis County.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Soil and yellow clay	20	0	20	0
Yellow limestone	15	0	35	0
Blue, gray, and black limestone	75	0	110	0
"Cotton rock"	65	0	175	0
Fine white sand		8	175	8
"Cotton rock," flint, and gray limestone	23	0	198	8
Gravel, white, gray, and black	1	4	200	0
Very dark lime and flint	15	0	215	0

At Smithton is a well owned by James Ringen and drilled by George Yeager. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Ringen well, Smithton, Pettis County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	3	3
Gravel	5	8
Clay	4	12
Gray limestone, yellow seams	28	40
Limestone and sand, some flint gravel	10	50
Crevice in rock; roar as if water running, but none was found.		
Cotton rock	20	70
Crevice; struck sand and plenty of water.		

RALLS COUNTY.

NADINE.

Three-eighths of a mile north of Nadine, Ralls County, in sec. 26, T. 53, R. 6, is a well owned by George W. Colvert. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Colvert well near Nadine, Ralls County.

	Thickness.	Depth.
	Feet.	*Feet.*
Solid clay	50	50
Gravel or shell rock	5	55
Hard rock, but not limestone	13	68
"Soapstone"	7	75
Slate	5	80
Coal	2½	82½
Fire clay	17½	100
Hard rock, limestone	89	189

PERRY.

Seven miles south of Perry, Ralls County, is a well owned by G. W. Allen and drilled by W. H. La Due. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Allen well near Perry, Ralls County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and yellow clay	40	40
Fire clay	40	80
Limestone rock	110	190
"Soapstone"	12	202
Brown lime rock	60	262
"Soapstone"	20	282
Lime rock	78	360
Sand rock	35	395

Six miles southwest of Perry is a well owned by John Clever and drilled by W. Smith. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Clever well near Perry, Ralls County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, clay, and drift	50	50
Flint and lime	16	66
Lime	124	190
Brownish-gray limestone	70	260
White limestone	62	322

RALLS.

At Ralls is a well owned by J. A. Clark and drilled by W. H. La Due. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Clark well, Ralls, Ralls County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil and yellow clay	20	20
Fire clay, or potter's clay	25	45
Lime rock, with a thin streak of "Soapstone," at 90 feet	305	350
Oil and gas rock	12	362
Limestone	48	410
Red sand rock	15	425
Limestone	15	440
White sandstone; water	5	445

RANDOLPH COUNTY.

HIGBEE.

At Higbee, in sec. 17, T. 52, R. 14, is a well owned by the city. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of well at Higbee, Randolph County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil		1
Soft clay	1	2
Hard clay	1	3
Sandy clay	7	10
Blue clay	10	20
Sand	5	25
Rock; water	3	28
Gravel	4	32
Clay	5	47
Sand rock	6	53
Limestone; water	7	60
Sandy clay	10	70
Sand rock	4	74
Limestone; water	6	80

The above beds all belong to the Des Moines group.

MOBERLY.

At Moberly, Randolph County, are several deep nonflowing wells. One-half mile west of the city the water company sunk two of these, 60 feet apart and 510 feet deep. The waters of these two wells are said to differ in composition and in amount. The deepest well in the immediate vicinity of these two is southwest of the waterworks and was drilled to a depth of 2,000 feet in search of oil. The writer is indebted to Mr. W. H. Jones, of Moberly, for the log of this well and other information. Mr. Jones states that salt water was struck between 800 and 900 feet. The percentage of salt steadily increased to a depth of 1,200 feet, below which the water became fresher. At a depth of 1,300 feet a hard magnesian water was struck, and at 2,000 feet the salt could scarcely be tasted. At 900 feet 5 gallons of water yielded, on evaporation, 1 pound of salt.

The meager records obtained from various wells drilled in this vicinity seem to indicate that there is a buried channel having a northeast-southwest trend, as wells situated a few hundred feet apart demonstrate the existence of an ancient valley or trough in the rock.

The log of the Moberly well is as follows:

Log of deep well at Moberly, Randolph County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (38 feet):		
Soil and gravel	38	38
Des Moines (79 feet):		
Shale	60	98
Fire clay	7	105
White sand	12	117
St. Louis limestone (19 feet):		
Blue and white limestone	19	136
Keokuk limestone (84 feet):		
Gray sand and limestone	84	220
Burlington limestone (75 feet):		
Blue and white marble	20	240
White marble	10	250
Limestone and sand	30	280
White limestone	15	295
Kinderhook (212 feet):		
Blue limestone	105	400
Blue limestone with slate seams	20	420
Blue slate	10	430
Gray limestone	5	435
Gray slate	2	437
Gray limestone	55	492
Blue sand	15	507
Devonian (68 feet):		
Gray limestone	45	552
Yellow sand	18	570
White slate	5	575
"Niagara" limestone (95 feet):		
White limestone	7	582
Blue limestone	12	594
Green slate	3	597
Gray limestone	5	602
White sand; water	20	622
Yellow sand	45	667
Slate; cased 9¾-inch hole	3	670
"Hudson group" (234 feet):		
Limestone	42	712
Flake or egg-shell limestone; soft water	10	722
Gray limestone with flint and iron seams	70	792
Gray sand	30	822

Log of deep well at Moberly, Randolph County—Continued.

	Thickness.	Depth.
"Hudson group"—Continued.	*Feet.*	*Feet.*
Gray limestone	8	830
Pebble sand; showing of oil	10	840
Gray sand	20	860
Limestone	4	864
Gray sand	5	869
Yellow sand	10	879
Blue limestone	15	894
Blue sand	8	902
Blue slate	2	904
"Trenton" limestone (131 feet):		
Limestone	28	932
Sand	18	950
Flint and limestone	80	1,030
White sand	5	1,035
Joachim limestone (55 feet):		
Limestone, flint, and sand	55	1,090
St. Peter sandstone (135 feet):		
White sand and flint	15	1,105
Blue sand and gray limestone	35	1,140
Salt, sand, and water	10	1,150
White sand; some sulphur water	52	1,202
Honeycombed sand	8	1,210
White sand	15	1,225
Undifferentiated Cambrian (465 feet):		
Limestone and flint	15	1,240
White limestone	10	1,250
White limestone and gray sand	72	1,322
Gray sand	19	1,341
Gray sand and limestone	27	1,368
White sand	5	1,373
Fine gray sand	12	1,385
Gray limestone	31	1,416
White sand	42	1,458
Blue limestone	17	1,475
Sand	163	1,638
Dark limestone or Trenton rock	12	1,650
Gray sand	40	1,690
No record	310	2,000

It is very probable that most of the sandstone in this record through the last thousand feet is really a siliceous limestone. Samples for study could not be obtained.

At 632 feet the largest amount of water, which was excellent for drinking purposes, was reached, in a white, transparent sandstone, the grains of which resembled granulated sugar. This was probably Devonian sandstone. At 870 feet salt water was reached; at 1,180 feet magnesia water, and at 1,215 feet very salty water, probably from the St. Peter sandstone. Water stood within 70 feet of the surface.

RANDOLPH SPRINGS.

On the southern slope of a small valley adjoining an old salt lick, about 5 miles west of Huntsville, near the east fork of Chariton River, is a well owned by Charles Dameron. Depth, 965 feet; altitude above tide, about 708 feet; temperature of water, 59° F.; of air, 83.5° F.; flow, weak; date of completion, about 1869; surface formation, Des Moines.

A few feet from the well is a strong brine spring; about 200 feet to the south, and slightly higher, is a chalybeate spring; 100 feet southeast of the latter, and still higher, is a shallow alum well; this group

constitutes the Randolph Springs. At one time this was a popular resort. Considerable water was then shipped to various points, and as early as 1824 salt was manufactured. When the well was sunk a careful log was kept, but it has, apparently, been lost.

Mr. Jacob S. Hunter, a member of the original company that sunk this well, writes that he thinks a moderate flow of sulphur water came from the last 100 feet. It is interesting to note that the water of the deep well is much less saline than that of the enighboring brine spring. This well was sunk in the hope of finding oil. The water contains a small amount of sulphureted hydrogen, and deposits a white precipitate. The flow is about 120 gallons per hour.

Schweitzer[a] states that the temperature of the water was 58° F., and the air temperature 65° F. in 1892, this being 1° cooler than was noted by the writer in 1904. The same author states:[a] "A partial analysis of the water of this well made more than ten years ago is printed in the appendix." On page 233 of the appendix he gives an analysis which must be referred to this well, but which he says is of water from the "salt spring." The following is a copy of this analysis:

Analysis of water from salt spring at Randolph Medical Springs.[b]

[Partly analyzed in March, 1881.]

	Parts per million.		Parts per million.
Silica (SiO_2)	4.5	Sulphate radicle (SO_4)	435
Aluminum (Al)	144	Chlorine (Cl)	3,304
Calcium (Ca)	248		
Magnesium (Mg)	52		5,793
Sodium (Na)	1,606		

In another place (pp. 81, 82) attention is called to the relation of some of these deep wells to adjoining springs and to the presence of calcium chloride as indicating fossil brines that were formed in basins shut off from the sea at an early period.

SALINE COUNTY.

MALTA BEND.

At Malta Bend is a well owned by the Saline Oil and Development Company. Its depth is 1,250 feet; altitude, 690 feet; casing, 8¼-inch, 789 feet; flow, 320 gallons per minute; temperature of water, 61° F.; of air, 82° F.; date of completion, July, 1903; driller, Walker Morton, Malta Bend. When this well was visited, in 1903, only a few samples of drillings—from 900 to 1,250 feet—could be had for

[a] Missouri Geol. Survey, vol. 3, 1892, p. 73.

[b] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

examination. The driller gave the missing data from memory, as follows:

Log of well at Malta Bend, Saline County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (119 feet):		
Soil	19	19
Quicksand, rounded flint bowlders at base	100	119
Des Moines (230 feet):		
Shale and sandstone	230	349
Mississippian (400 feet):		
Limestone	300	649
Softer, sandy limestone, and 10 feet bluish shale	100	749
Devonian and Silurian (?) (190 feet):		
Limestone	100	849
St. Peter sandstone (80 feet):		
Dark sand	50	899
Soft, coarse white sandstone, with rounded grains	30	929
Jefferson City limestone (225 feet):		
Siliceous magnesian limestone, with chert or blue flint with calcite crystals	225	1,154
Roubidoux sandstone (90 feet+):		
Reddish-white sandstone, rounded, polished grains	20	1,174
Siliceous magnesian limestone, with calcite crystals and pyrite, dark gray	75	1,249
Gray sandstone, fine rounded grains	1	1,250

No analysis of this water has been made. It is very strongly saline and highly charged with sulphureted hydrogen. It is one of the strongest flowing wells in the State.

SLATER.

At Slater, Saline County, a well was sunk in 1898 to a depth of 650 feet. It was cased for 70 feet with 10-inch casing, and 400 feet farther with 6-inch casing. The water, which contains considerable iron, rises within 150 feet of the surface, the main supply coming from the sandstone at the bottom of the well. It is pumped and used for domestic purposes and protection from fire. The water level is slightly lowered after continuous pumping.

SWEET SPRINGS.

About a quarter of a mile west of Sweet Springs, on the banks of Black Water River, is a well about which the following information was obtained: Depth, 1,074 feet; altitude, about 670 feet; casing, 8-inch, 29 feet to rock; temperature of water, 62° F.; of air, 84° F.; date of completion, 1902; driller, Jack Hume; cost, about $3,000; surface formation, Burlington limestone, under Pleistocene.

Log of well at Sweet Springs, Saline County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (29 feet):		
Soil	27	27
Gravel and sand	2	29
Mississippian (326 feet):		
Limestone	41	70
Soapstone	10	80
Limestone	1	81
Soapstone	12	93
Brown limestone	92	185
Sandstone	42	227
Limestone	33	260
Bastard limestone and gravel	12	272
Gray limestone	48	320
White sandstone	35	355

Log of well at Sweet Springs, Saline County—Continued.

	Thickness.	Depth.
Devonian and Cambrian (719 feet):	*Feet.*	*Feet.*
Gray limestone	4	359
Gray sandstone	30	389
Soft limestone	3	392
Brown sandstone	8	400
Soft gray limestone	2	402
Sandstone	76	478
Gray limestone	2	480
Sandstone	59	539
Limestone and sandstone	10	549
Sandstone	75	624
Dark gray, very coarse sandstone	12	636
Gray sandstone	25	661
Coarse sandstone	2	663
Sandstone	411	1,074

According to the statement of the driller the first flow of water, which was weak, was struck at a depth of 300 feet, just above what is believed to be the Hannibal sandstone, this formation being found at depths of 320 to 355 feet. The St. Peter sandstone should be located either between 402 and 478 feet, which would give a thickness of 76 feet; or, as is more probable, between 557 and 624 feet, which would give a thickness of 67 feet. At 564 feet the strongest flow of water was obtained, and at 604 feet the first strong saline water was found, facts which would seem to indicate that the St. Peter sandstone is the water-bearing horizon in this section. It is quite probable that some of the strata marked "sandstone" in the driller's record may have been siliceous limestone. This has been the case in a number of other instances where the writer has had the opportunity of comparing the drillings with the log. Men who have been accustomed to drilling mainly in the sandstones and shales of the Pennsylvanian are very liable to confuse the siliceous limestones and cherts with sandstones.

The water gushes out with great force from an 8-inch pipe, which is 15 feet high, with an elbow at the top. The flow is about 840 gallons per minute. When the well was first opened a pipe 44½ feet long was attached, and the stream was carried with force above that height. The water is clear, strongly saline, and charged with sulphureted hydrogen. It deposits a white precipitate on pipe, stones, and soil. No analysis has been made.

WARREN COUNTY.

WARRENTON.

At Warrenton, Warren County, in sec. 28, T. 47, R. 2, there is a well 400 feet deep, at an altitude of 875 feet. It has a 6-inch casing for about 100 feet to rock. The well was completed in 1891. A small flow of water was struck at 150 feet, but the main supply was obtained at 360 feet. The water, which is rather hard, is used for a steam mill and town supply. The cost of the well and pumping

machinery was about $900. The following log, together with other information, was furnished by Prof. John H. Frick:

Log of well at Warrenton, Warren County.

	Thickness.	Depth.
	Feet.	*Feet.*
Drift clays	80	80
Chert, clay, and gravel	16	96
Limestone	50	146
Sandy limestone	1	147
Light gray limestone	13	160
Blue clay	40	200
Gray limestone	108	308
"Soapstone"	44	352
St. Peter sandstone	48+	400

This well started in the Mississippian.

DECATURVILLE DOME DISTRICT.

The Decaturville dome district includes an area in Camden, Hickory, Miller, and Polk counties within a radius of about 30 miles from Decaturville, Camden County. The district is small and is somewhat arbitrarily defined. Flowing wells are located at or near the following places: Carver, Decaturville, and Hahatonka, Camden County; Aurora Springs and Iberia, Miller County; Cross Timbers and Pittsburg, Hickory County; Cliquot and Goodson, Polk County.

CAMDEN COUNTY.

CARVER.

Two miles northwest of Carver, on the east side of the road between Climax Springs and Proctor, in sec. 29, T. 40, R. 18, in a valley about 60 feet above Osage River, is a well owned by James Hildebrand, and drilled by John Hays, of Versailles, with a diamond-core drill. This well was completed in 1901. It is 901½ feet deep, with a 2-inch bore. The water, which is clear, soft, and rather warm, rises 30 feet above the surface. No variation in flow has been noticed. The well probably started in the Gasconade limestone.

DECATURVILLE.

At Decaturville, on the southern border of Camden County, the intrusion of a dike of pegmatite has greatly tilted the rocks for 10 to 15 miles around, producing conditions favorable for artesian wells.[a]

Nine hundred feet west of Samuel Wheeler's place, near Decaturville, J. N. Kennett sunk a well 300 feet deep for mineral. A strong

[a] For further description of this interesting locality, see Shepard, E. M., The spring system of the Decaturville dome, Camden County, Mo.: Water-Sup. and Irr. Paper No. 110, U. S. Geol. Survey, 1905, p. 113.

flow was struck at a depth of 200 feet. This continued for s years, but gradually declined until all activity ceased. The mo this well is about 50 feet lower than Pegmatite Hill.

GUNTERS.

The Rust and Scott wells are situated on the land of Tip W 1 mile west of Gunters, on the west side of Banks Creek, near it tion with Niangua River, and are separated from the Kellogg we ridge 200 feet high. These two holes were bored for mineral in

The Rust well, to the north, is 780 feet deep. The first flow of was obtained at 680 feet. The temperature of the water is 5 and that of the air is 84° F. Colonel Scott states that the which is clear and sparkling, with a slight odor of sulphureted h gen, rises 30 feet above the surface. No decrease in pressure has noted.

The Scott well is 740 feet deep, and is situated an eighth of a from the Rust well, on the same side of the branch and close The first flow was struck at 680 feet. The original pressure was cient to raise the water 20 feet above the surface, but now (19 simply flows at the surface. The temperature and other ph characters are the same as in the Rust well.

Partial analyses of a number of wells and springs in this r including Bennett's and Gunter's springs and the Lebanon well a similar character and composition in all, a fact which points deep-seated origin of all these waters, and seems to indicate a co source in the catchment basin around Pegmatite Hill. The pr in a number of these waters of a small amount of sodium carb apparently confirms this view, and shows that the pegmatite c ing soda feldspar is of greater extent underground than at the s

HAHATONKA.

In 1902 Major Rush sunk a well in search of mineral on the west side of Hahatonka Lake, not far from the island and bu feet above the level of the lake. It is 864 feet deep. The fir of water was obtained at 840 feet. The water rose 36 feet the surface. This well was started probably near the top Gasconade limestone and ended in 3 feet of soft sandstone, p of the Elvins formation. Unfortunately no record was obta The flow has materially decreased. The temperature of the is 63° F. with an air temperature of 87° F. The water is ch warmer than that of adjacent springs, and has a slight o sulphureted hydrogen.

HICKORY COUNTY.

CROSS TIMBERS.

Five miles due west of Cross Timbers, in the bottom of a small stream valley, in the NW. ¼ NW. ¼ sec. 24, T. 38, R. 22, are three wells owned by G. W. Crudginton that were drilled in September, 1899, in prospecting for lead and zinc, to the depths of 75, 90, and 110 feet. Water began to flow from a depth of 33 feet, and continued to do so all the way down. No perceptible change in the flow has ever been noted. The three wells are all within 50 yards of one another, and at about the same elevation, which is estimated, barometrically, as 535 feet. It is difficult to determine the flow of these wells, as a large amount of water leaks out from the base of the pipes. The well with the strongest pressure has a flow, from a 2½-inch pipe, estimated at about 8 gallons per minute. These drill holes had originally a 6-inch bore and were never cased. No log was kept, but it is stated that they passed through limestone all the way, probably starting in the Roubidoux. The following analysis of the water from the deepest of the three wells was made by Mr. E. E. Ellis, to whom the writer is indebted for these notes.

Analysis of water from well No. 3 at Cross Timbers, Hickory County.

	Parts per million.		Parts per million.
Iron	Trace.	Sulphates	88
Calcium	380	Chlorides	14.44
Total hardness	152.9	Temperature of air, 64.2° F.	
Total carbonates	470.4	Temperature of water, 57.2° F.	
Alkaline carbonates (normal)	0	Color, clear.	
Alkaline earthy carbonates (acid)	470.4	Odor, none.	

The water has a slight odor of sulphureted hydrogen.

PITTSBURG.

In 1896 the discovery of zinc in a shallow well started a large amount of prospecting in the neighborhood of Pittsburg, and several flowing wells were obtained from these prospect holes. These wells seem to be located on the northwestern slope of a fold extending northeast and southwest through this region, and have been placed, for convenience of description, in the Decaturville dome district.

Pittsburg is situated in the southeast corner of sec. 25, T. 36, R. 22, at an altitude, barometrically, of 1,155 feet, or 90 feet above the town of Bolivar. The first flowing well was struck on the land of J. A. Williams, in the northwest corner of sec. 25, T. 36, R. 22. It was drilled by Mr. Busby, of Iola, in August, 1901, with a 6-inch churn drill, to a depth of 100 feet, and cost $75. Water was encountered at

depth of 20 feet, but the first flow came from near the bottom. The mouth of the well is a little less than 100 feet lower than the town of Pittsburg, and is probably in the Jefferson City limestone. No log was kept, but it is stated that the drill passed through limestone all the way. No variation has been noted in the flow, which is a small stream. The water is clear and odorless. The air temperature is 48° F., and the water temperature 53° F.

The well on the land of S. J. Martin, south of the center of the SW. ¼ sec. 25, T. 36, R. 22, was sunk in October, 1901, to a depth of 100 feet, with a 6-inch churn drill. This well had at first a stronger flow than any other in this group, but the force has gradually diminished until the water stands 3 feet below the surface.

The well on the land of Y. J. Petts, in the center of the W. ½ sec. 36, T. 36, R. 22, on the top of a hill, is 90 feet deep, and was made with a 6-inch churn drill. The well was started in the upper part of the Burlington limestone about 8 feet thick, then passed through 10 feet of yellow rock (Chouteau limestone) and 20 feet of blue (Hannibal) shale. The remainder of the record was lost. The absence of the lower part of the Burlington all through this region is noticeable. The air temperature is 48° F., the water temperature 53° F.

A well near the center of sec. 14, T. 35, R. 22, owned by Len. G. Mallonnee, of Pittsburg, was sunk to a depth of 110 feet, in October, 1901, with a 6-inch churn drill. This well was started in white, coarse-grained limestone (the upper part of the Burlington), 30 feet thick; it then passed through 30 feet of sandstone (Hannibal), 20 feet of blue shales (Hannibal), and flint to the bottom. It is noticeable that the Chouteau limestone is absent. The water is colorless and odorless. It was struck in the Hannibal sandstone, and did not flow until the sandstone was nearly passed through, after which the flow grew stronger until the bottom was reached.

MILLER COUNTY.

AURORA SPRINGS.

A little to the southeast of Aurora Springs, Miller County, in sec. 19, T. 41, R. 15, a shaft was sunk to a depth of 140 feet, in prospecting for lead and zinc. The well is situated about 12 feet above the bottom of Little Gravois Creek. No water was struck until a depth of 100 feet was reached; below this the well commenced to flow.

IBERIA.

Two and one-half miles northwest of Iberia, in the bottom of Baileys Branch, is a well on the farm of George Graves. A moderate flow of water was obtained at a depth of 60 feet, in the Gasconade limestone.

POLK COUNTY.

CLIQUOT.

Near Cliquot are two wells—one owned by the St. Louis and San Francisco Railroad and the other by M. C. Shelton.

The railroad well, in sec. 8, T. 34, R. 23, was drilled in 1901 by W. A. Hash, of Bolivar, to a depth of 262 feet, the first 196 feet with an 8-inch bore and the last 66 feet with a 6-inch bore. Water was struck at 40 feet, and the flow increased slowly with the depth. The pressure is sufficient to raise the water in a pipe 15 or 20 feet above the surface. A pump is, however, used to force the water into a water tank for engine purposes. The water is clear, colorless, odorless, and cool. The well starts in what is probably the base of the St. Peter sandstone. The altitude of Cliquot is about 995 feet.

The Shelton well is situated in the center of sec. 17, T. 34, R. 23, three-fourths of a mile southeast of Cliquot, and probably 50 feet higher than the well at that point. It is only 10 feet deep, and passed through a tough yellow clay and shale, striking a hard rock at 10 feet, from which point the water rose and flowed out at the surface. The shale was, undoubtedly, Hannibal shale, and the limestone either Louisiana or "Sac" limestone.

GOODSON.

Near Goodson post-office, 9 miles south and 3 miles east of Pittsburg, is a well that was originally a prospect hole for lead and zinc. It is 100 feet deep and has a good flow, the water rising 6 feet above the surface.

CLINTON-NEVADA DISTRICT.

GENERAL ARTESIAN CONDITIONS.

The Clinton-Nevada district includes portions of Henry, Vernon, Cass, Bates, St. Clair, and Cedar counties. The wells in this district have their catchment basin in the Ozarks. The uniform dip of the strata to the west and northwest is continued in this district as in the districts to the north. In this district, however, the conditions are more favorable for flowing wells than farther north, as the altitude of the country to the west does not increase so rapidly.

The upturned edges of the Pennsylvanian rocks outcrop successively through this district. Fairly good water is obtained from the sandstones and limestones of the Pennsylvanian, but that from the shales is liable to be strongly saline. The Mississippian forms a fine water table, and a strong body of water is usually found when the drill reaches that series.

Large shallow ponds or lakes and swamps extend in a long narrow belt from a point southwest of Nevada for a distance of 40 miles to the northwest. Some of these bodies of water cover several hundred

acres and are never dry. The peculiar topography and conditions so far south of the glaciated area immediately impress the observer. It is said that these ponds contain fresh, pure water and are spring fed. It is also stated that a person wading in them can feel the cold jets of water that come up from many points all over the bottom. This belt of lakes and swamps seems to be a flat, slightly depressed area with a somewhat abrupt eastern side that rises suddenly to a broad valley or plain from 40 to 60 feet above the lake valley. This outline suggests the possibility that the area has been undermined by the numerous springs brought up by artesian pressure, the phenomena being similar to those observed in the "sunk district" of southeastern Missouri. Flowing wells are found at the following places: Clinton, Henry County; Nevada, Richards, Sheldon, and Stotesbury, Vernon County; and near Horse Creek, Barton County.

BARTON COUNTY.

HORSE CREEK.

In the middle of the N. ½ sec. 2, T. 33, R. 29, just above the level of a little branch that flows into Horse Creek, is a well that was sunk in 1884 to a depth of 60 feet in search for mineral. It was started near the base of the Cherokee shales and stopped at the top of the Mississippian limestone. It flows a very small stream, which is piped laterally. The water contains a very small amount of gas. Its temperature was 64° F. when that of the air was 87° F.

BATES COUNTY.

ADRIAN.

In sec. 30, T. 42 N., R. 30 W., is a well owned by the Lawder estate and drilled by R. J. Lawder. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Lawder well, Adrian, Bates County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, red and yellow clay	37	37
Lime rock	3	40
Fire clay	20	60
Lime rock	11	71
Dark clay	4	75
Lime rock	3	78
Gray slate	10	88
Dark clay	3	91
Lime rock	5	96
Gray slate	14	110
Blue soapstone	20	130
Fire clay	17	147
Lime rock	7	154
Blue joint clay	10	164
Lime rock	8	172
Gray joint clay	4	176
Flint rock	8	184
Gray clay	2	186
Gray lime rock; affords about 2 barrels of water per day	74	260
Sand rock	15	275
White lime rock	25	300
Sand rock	20	320

ROCKVILLE.

In 1904 a well was drilled at Rockville to a depth of 1,550 feet. The driller declined to give a full record, but from his statement it was learned that the St. Peter sandstone was reached at a depth of 856 feet, with a strong body of saline water.

CASS COUNTY.

DREXEL.

In Drexel, Cass County, is a drilled well 64 feet deep. It penetrated 40 feet of limestone and 4 feet of carbonaceous shale, from which latter the water is derived. The water is pumped to the surface and has a temperature of 58° F.

Schweitzer, in his report on the mineral waters of Missouri,[a] gives the following analysis:

Analysis of water from well at Drexel, Cass County.[b]

	Parts per million.		Parts per million.
Silica (SiO_2)	11	Sulphate radicle (SO_4)	74
Iron (Fe)	2.8	Chlorine (Cl)	103
Calcium (Ca)	9.9	Sulphur (S)	4.1
Magnesium (Mg)	6.5		
Sodium (Na)	481		1,751.3
Bicarbonate radicle (HCO_3)	1,059		

PLEASANT HILL.

At Pleasant Hill, Cass County, there is a well 150 feet south of the Missouri Pacific Railway. The log, for which the writer is indebted to Dr. G. C. Broadhead, is as follows:

Log of well at Pleasant Hill, Cass County.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Dark clay	30		30	
Gravel, water-bearing	2		32	
Clay, with thin layers of sandstone	43		75	
Black bituminous shale, with streak of coal	3		78	
Dark shales, with thin limestone layer	2		89	
Dove-colored shales	9		89	
Gray limestone	5		94	
Dove-colored calcareous shales	7		101	
Dark shales with red beds	2	6	103	6
Shales	28		131	6
Sandstone	3		134	6
Shales and limestone	17		151	6
Black shales, with thin coal seams	3		154	3
Shales and clay	3		157	6
Blue limestone	10		167	6

[a] Missouri Geol. Survey, vol. 3, 1892, p. 182.

[b] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

Log of well at Pleasant Hill, Cass County—Continued.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Dark shales and sandstone	7		174	[illegible]
Dark-blue and red shales	15		189	[illegible]
Hard blue limestone	2		191	[illegible]
Dark shales and coal	1	6	193	
Clay	2		195	
Sandstone	10		205	
Limestone	2		207	
Sandstone	3		210	
Shales and coal	1		211	
Alternating sandstone and shales	80		291	
Dark shales	1		292	
Shales	9		301	
Bituminous slate	3		304	
Sandstone and shales	18		322	
Shale, slate, and a foot of coal	2		324	
Sandstone and shales with pyrite	31		355	
Limestone	1		356	
Shales	3	6	359	[illegible]
Good bituminous coal	1	6	361	
Fire clay, with nodules of ironstone	5		366	
Clay, shales, and ironstone	10		376	
Micaceous sandstone with some clay	105		481	
Dark clay with 1 foot of coal	5		486	
Sandstone and blue shales with pyrites	47		533	
Shale	19		552	
Brown sandstone	28		580	
Lower Carboniferous limestone and chert	25		605	

All but the last 25 feet of this section is Des Moines.

HENRY COUNTY.

CLINTON.

At Clinton, Henry County (see fig. 5), the Clinton Light and Water Company has several wells.[a] Well No. 1, south of the city, in the NW. ¼ SW. ¼ sec. 10, T. 41, R. 26, was drilled in the summer of 1897. Depth, 800 feet; altitude, 700 feet above tide; casing, 8-inch to 425 feet, 5⅝-inch to 800 feet; flow, 400 gallons per minute; cost, about $2,500; surface formation, base of Cherokee shales. The first flow of water noted, 75 gallons per minute, was obtained at a depth of [illegible] feet in the St. Peter sandstone. At 425 feet the flow had increased to about 200 gallons per minute and the pressure was so strong that it was difficult to preserve the drillings. This water was charged with sulphureted hydrogen and was called sulphur water. At this depth the bore was reduced from 8 to 5⅝ inches, and continued thus down to 800 feet. The flow of water at 425 feet was cut off by casing, so that the two distinct flows could be obtained, that from the depth of 425 feet issuing from around the inner casing, which brought up the water from 800 feet. The water from the bottom was probably derived

[a] Acknowledgment is hereby made to Dr. J. H. Britts, of Clinton, for the drill samples which the writer has examined, for records and analyses of this interesting group of wells and for other valuable information.

from the base of the Gasconade limestone and was fresh. The flow in both cases was measured and found to be about 200 gallons per

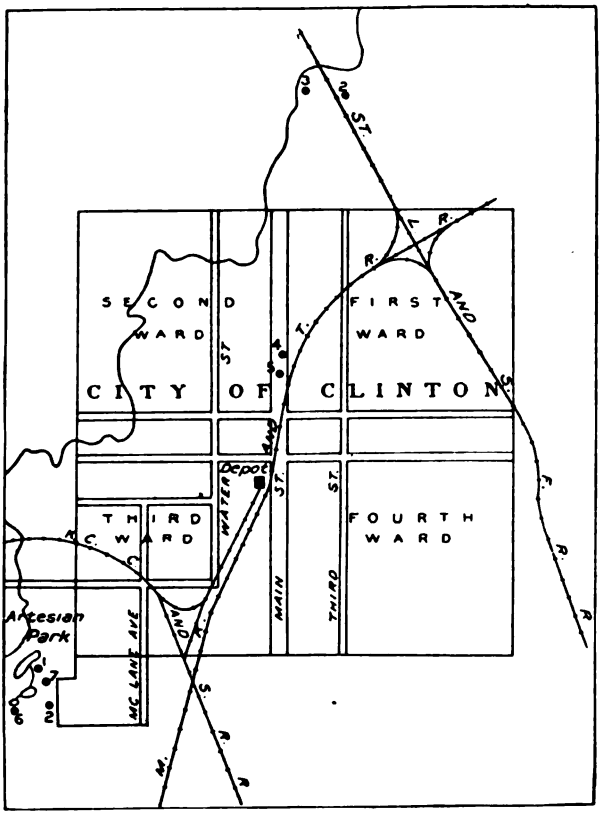


FIG. 5.—Map of the Clinton artesian district, Henry County.

minute each, or a total of 400 gallons. The inner casing has since been removed, and the waters mix. The following is the record of this well:

Log of artesian well (No. 1), Clinton, Henry County.

	Thickness.	Depth.
	Feet.	*Feet.*
Des Moines (40 feet):		
Blue shale	40	40
Keokuk and Burlington (80 feet):		
Chert and gray limestone	10	50
White chert	10	60
White chert and limestone	20	80
White shaly limestone	10	90
Gray limestone and white chert	10	100
Blue magnesian shale	10	110
Blue and gray siliceous limestone and chert	10	120

Log of artesian well (No. 1), Clinton, Henry County—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Chouteau limestone (70 feet):		
Light-gray crystalline magnesian limestone, little chert	25	145
Blue splintery, compact magnesian limestone	15	160
Blue splintery, shaly magnesian limestone	20	180
Same, with more chert	10	190
Devonian (40 feet):		
Same, with more chert and siliceous limestone	10	200
Blue and gray shaly, siliceous magnesian limestone	20	220
Gray siliceous magnesian limestone, some chert	10	230
Joachim limestone (50 feet):		
Light-gray "cotton rock," magnesian limestone	30	260
Same and some blue limestone	20	280
St. Peter sandstone (30 feet):		
Fine-grained blue chalcedonic flint, siliceous limestone with marcasite crystals and iron-stained sand (rounded grains of quartz)	10	290
Same, with finer rounded grains (probably St. Peter sandstone)	10	300
Coarser, more rounded grains of quartz, siliceous white magnesian limestone	10	310
Jefferson City limestone (190 feet):		
Quartz, flint, and siliceous magnesian limestone, minute marcasite crystals	10	320
Flint and quartz grains mixed with siliceous limestone	10	330
Same, with minute marcasite crystals and iron stain	10	340
Fine-grained siliceous dolomitic limestone, with some flint	30	370
Gray siliceous dolomite, white flint and marcasite	10	380
Gray siliceous dolomite, slightly coarser, no flint	10	390
Dark-gray siliceous dolomite, with few coarse particles of flint	10	400
Flint, quartz, and siliceous limestone; flow of water very strong; sulphur water at 425 feet	100	500
Roubidoux sandstone (25 feet):		
Fine white sandstone (probably Second sandstone of Swallow); flow very strong	25	525
Gasconade limestone (275 feet):		
(From 525 to 670 feet no cuttings could be had owing to force of water)	145	670
Light bluish-gray dolomite, with fine grains of white flint	30	700
Fine grains of quartz, white flint, and gray siliceous dolomite at bottom; fresh water	100	800

The following analysis is taken from Schweitzer's report.[a]

Analysis of water from artesian well (No. 1), Clinton, Henry County.[b]

[Analyst, A. E. Woodward, 1892.]

	Parts per million.		Parts per million.
Silica (SiO_2)	12	Bicarbonate radicle (HCO_3)	375
Calcium (Ca)	117	Sulphate radicle (SO_4)	110
Magnesium (Mg)	51	Chlorine (Cl)	719
Sodium (Na)	419		1,819
Potassium (K)	16		

This is a distinctly saline water, with a small percentage of carbonates present. The sample for analysis was obtained by plunging a gallon bottle into the mouth of the standpipe and allowing it to fill with the water. The bottle was then stoppered and sealed with melted paraffin.

Well No. 2 is a few hundred feet south of well No. 1. Depth, 800 feet; altitude above tide, 700 feet; casing, 5-inch to bottom; flow, about 200 gallons per minute;[c] date of completion, 1891; surface formation, base of Cherokee shales. The log of this well is essentially the same as that of No. 1. It is a curious fact, however, that the

[a] Mineral waters of Missouri: Missouri Geol. Survey, vol. 3, 1892, p. 86.

[b] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

[c] Since the sinking of well No. 7 the flow of this well has decreased fully one-half.

chemical composition of the water is decidedly different, as may be seen by a comparison of the accompanying analyses of the two.[a] This well was for a number of years the main source of water supply for the city of Clinton. The water is collected in large reservoirs and, together with that of several other wells more recently drilled, is pumped to the city.

Analyses of water from artesian well (No. 1) and waterworks well (No. 2), Clinton, Henry County.[b]

[Parts per million.]

	Artesian well.	Waterworks well.
Calcium (Ca)	116	80
Magnesium (Mg)	51	37
Sodium (Na)	420	204
Potassium (K)	17	42
Carbonate radicle (CO_3)	184	168
Sulphate radicle (SO_4)	110	91
Chlorine (Cl)	717	335
	1,615	957
Free H_2S	4.1	1.1
Free CO_2 and combined as bicarbonate	175	147

In connection with this comparison Woodward says:

Since the two wells are but a short distance apart and were both drilled to the same depth, a correspondence between the analyses of these waters is to be expected. A very considerable difference is found to exist, however. Thus, though both are characterized by a large percentage of sodium and chlorine, the water of this well [waterworks well] differs from the artesian-well water by containing larger amounts of carbonates and sulphates. These differences are produced probably by the mixing in the waterworks well of a greater quantity of surface waters with the chloride water, thereby decreasing the amount of total solids and increasing at the same time the amount of alkaline constituents. * * * Results of analyses of other well or spring waters directly comparable to these Clinton waters are not easy to find. The Fort Scott, Kans., artesian water yielded 1,868 parts per million; the Clinton artesian, 1,615 parts per million.

The following is a complete analysis of water from waterworks well (No. 2):[c]

Analysis of water from waterworks well (No. 2), Clinton, Henry County.[b]

[Analyst, A. E. Woodward, 1892.]

	Parts per million.		Parts per million.
Silica (SiO_2)	2.4	Bicarbonate radicle (HCO_3)	342
Calcium (Ca)	80	Sulphate radicle (SO_4)	91
Magnesium (Mg)	37	Chlorine (Cl)	335
Sodium (Na)	204		
Potassium (K)	42		1,133.4

[a] Woodward, A. E., Bull. Missouri Geol. Survey No. 3, 1890, p. 91.

[b] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

[c] Schweitzer, Paul, Mineral waters of Missouri; Missouri Geol. Survey, vol. 3, 1892, p. 120.

About 1 mile north of the wells previously described, in the bottom of the same creek and similar in character to No. 2, is a well (No. 3) owned by Dr. J. H. Britts. Depth, 913 feet; altitude above tide, 715 feet; casing, 8-inch to bottom; temperature of water, 64° F.; flow, 400 gallons per minute;[a] date of completion, 1891; cost, $2,000; surface formation, base of Cherokee shale. The log of this well differs slightly from those of the other wells in the first 60 feet, the first 40 feet of Cherokee shales being followed by 20 feet of Graydon sandstone, a formation which does not appear in any of the other wells about Clinton. The following is an analysis of the water of the Britts well:[b]

Analysis of water from Britts artesian well (No. 3), Clinton, Henry County.[c]

[Analyst, Paul Schweitzer.]

	Parts per million.		Parts per million.
Silica (SiO_2)	14	Bicarbonate radicle (HCO_3)	[illegible]
Calcium (Ca)	106	Sulphate radicle (SO_4)	[illegible]
Magnesium (Mg)	45	Chlorine (Cl)	[illegible]
Sodium (Na)	353		
Potassium (K)	19		1,[illegible]

At the Clinton ice plant, about 1,000 feet northeast of the courthouse, at one of the highest points in the vicinity, are two nonflowing wells (Nos. 4 and 5), 10 feet apart. One was drilled in 1894 and the other in 1896. Both are 650 feet deep and their altitude is 780 feet, which is probably 80 feet more than that of the flowing wells in the valley. The bore of one is 8 inches and of the other 2 inches. Water rises within about 100 feet of the surface. The wells are equipped with two deep-well pumps having a capacity of 240 gallons per minute, and they would undoubtedly supply two or three times the capacity of the pumps. No analysis of the water of either of these wells has been made, but it is stated that it is alkaline with an appreciable amount of sulphureted hydrogen, and similar in character to that of the other wells. Marbut[d] gives the following log of these wells:

Log of wells at Clinton ice plant (Nos. 4 and 5), Clinton, Henry County.

	Thickness.		
	Ft.	In.	[illegible]
Soil and clay	12	0	[illegible]
Sandstone and sandy shale	21	0	[illegible]
Coal	0	4	[illegible]
Shale	5	0	[illegible]
Sandstone, very hard	8	0	[illegible]
Shale and sandstone	87	[illegible]	[illegible]
Chert, lower Carboniferous	45	[illegible]	[illegible]
Shale, red	50	0	[illegible]
Limestone, Lower Carboniferous and Silurian	[illegible]	0	[illegible]
Sandstone, "Saccharoidal," with rounded grains of pure silica	40	0	[illegible]

[a] Since the completion of well No. 7, near Nos. 1 and 2, this well has ceased to flow.

[b] Missouri Geol. Survey, vol. 3, 1892, p. 121.

[c] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at [illegible] States Geological Survey.

[d] Marbut, C. F., Geology of the Clinton sheet: Missouri Geol. Survey, vol. 12, pt. 2, 1898, p. [illegible]

About 200 feet west of well No. 2 is a well (No. 6), owned by the Clinton Light and Water Company. Depth, 500 feet; altitude above tide, 700 feet; casing, 8-inch to bottom; flow, 200 gallons per minute;[a] date of completion, 1897; surface formation, base of Cherokee shales. The water of this well is similar in composition to that of well No. 2, and the two wells have similar logs. The water is collected in settling basins for city service.

Near the northeast corner of the new settling basin of the Clinton water station about 150 feet north of well No. 2 is another well (No. 7), owned by the Clinton Light and Water Company. Depth, 818 feet; altitude above tide, 700 feet; casing, 10-inch to bottom; flow, about 700 gallons per minute; date of completion, February, 1902; cost of well, $2,000; surface formation, base of the Cherokee shales. The flow of this well surpasses that of all of the other wells combined, and its effect on the others, as has already been mentioned, has been marked. The water resembles that of No. 2 more closely than that of any of the other wells. It may be classed as an alkaline water, with some sodium chloride and with free hydrogen-sulphide gas. It is not, however, a combined sulphur water. This well is at present the main source of the city water, which it supplies in the greatest abundance, filling a reservoir 250 by 160 by 5 feet in twelve hours. The log is practically the same as that of the other Clinton wells, extending into the Gasconade limestone. The main source of water is probably in the Roubidoux sandstone. This well began to flow at about 375 feet and the water was comparatively soft with but little mineral salts and hydrogen-sulphide gas. The flow gradually increased with the depth of the well with a corresponding increase of mineral constitutents. The following analysis of this water was obtained:

Analysis of water from well No. 7, Clinton, Henry County.[b]

[Analyst, J. C. Draper, June 20, 1902.]

	Parts per million.		Parts per million.
Silica (SiO_2)	6.4	Sulphate radicle (SO_4)	122
Iron (Fe)	Trace.	Chlorine (Cl)	122
Calcium (Ca)	147	Alkaline chlorides	1,562
Magnesium (Mg)	56		
Carbonate radicle (CO_3)	179		2,194.4

The Jordan well is located in sec. 19, T. 41, N., R. 25 W., about 3 miles southeast of Clinton. It flowed feebly for a number of years after it was drilled and yielded a mildly chalybeate water, which was extensively used. It is now, however, abandoned and choked up. No log was kept and no analysis was made, but the water apparently had its source in the Cherokee shales.

[a] Flow has decreased since the sinking of well No. 7.

[b] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

ST. CLAIR COUNTY.

APPLETON.

In 1891 the Appleton City Water and Power Company put down a well 1,190 feet deep in prospecting for oil, gas, or water. It is to be regretted that the greater portion of the record of this well has been lost. It was cased for 300 feet with 8-inch casing. A strong body of water was struck between 1,000 and 1,100 feet. It was decidedly saline, and contained a large amount of sulphureted hydrogen. The mouth of the well has an altitude of 760 feet; the well starts in Cherokee shales, and water stands 40 feet from the surface. Acknowledgment is made to Mr. T. C. Brown for the use of such drill samples as have been preserved. The well cost $2,000. At 50 and 150 feet small coal seams were struck.

From the cuttings that have been preserved, Mr. Ellis gives the following incomplete log:

Partial log of well at Appleton City, St. Clair County.

	Thickness.	Depth.
	Feet.	*Feet.*
Grayish-brown compact limestone containing numerous small, well-rounded quartz grains, at		[illegible]
Compact limestone and chert, with small rounded quartz grains	21	[illegible]
Finely crystalline dark-brown limestone, with some chert and many rounded quartz grains	[illegible]	[illegible]
Thoroughly crystalline, fine-grained gray limestone, with small amounts of chert and marcasite	[illegible]	[illegible]
Compact, crystalline grayish-brown limestone, with oolitic chert and sand	[illegible]	[illegible]
Finely crystalline, light-gray limestone, with few sand grains; no chert	[illegible]	[illegible]
Rather fine-grained sandstone, nearly white, iron-stained, grains well rounded	[illegible]	[illegible]
Crystalline light-gray limestone, with white chert	[illegible]	[illegible]
Compact light-gray limestone, with some sand grains	[illegible]	[illegible]

The greater part of this section is probably Gasconade limestone.

Analysis of water from artesian well at Appleton City, St. Clair County.

[Analyst: Paul Schweitzer.]

	Parts per million.		Parts per million.
Silica (SiO_2)	40	Carbonate radicle (CO_3)	[illegible]
Calcium (Ca)	369	Sulphate radicle (SO_4)	[illegible]
Magnesium (Mg)	161	Chlorine (Cl)	[illegible]
Sodium (Na)	2,589		
Lithium (Li)	10		[illegible]

This water was used by the city for two years, being pumped by a small engine, but it was finally discarded because of its highly mineralized character. It is stated that the water corroded iron and tin and killed neighboring vegetation.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to form and parts per million at United States Geological Survey.

OSCEOLA.

In 1891 a well about 500 feet deep, with an 8-inch bore, was sunk in Osceola and cased 12 feet to rock. A strong vein of water was struck, which rose within 75 feet of the surface. The water is hard, and was pumped for general use. The cost of the well was $1,500.

Another well is now (summer of 1905) being drilled at Osceola for oil and gas by the Osceola Development Company on the farm of M. M. Love, 1 mile west of the Frisco Railway station, on the top of a hill having an elevation of 832 feet. The well was started in the base of the Des Moines, and the company expects to go to a depth of 1,800 feet.

VERNON COUNTY.

NEVADA.

Nevada, Vernon County, is, like Clinton, the center of a group of several flowing and nonflowing deep wells. The oil excitement in Kansas stimulated the boring of deep holes in this region, which resulted in the finding of several valuable artesian wells in this county. The most important of these are the wells at Nevada, Sheldon, Stotesbury, and Walker.

In the suburbs of Nevada, a little over a mile from the railway station, is a well owned by Harry C. Moore. Depth, 800 feet; altitude, barometrically, 900 feet; casing, 6-inch; depth, unknown; temperature of water, 63° F.; of air, 69° F.; flow, 10,000 gallons per hour; date of completion, 1887; cost, $2,500; surface formation, base of Cherokee shales. The well is situated on the side of a valley at the foot of a low ridge. The water rises through an iron pipe and flows into a basin, whence it is conveyed to two lakes covering 15 acres each. The water is strongly impregnated with sulphureted hydrogen and a deposit of white algæ, the same as that at Clinton, covers the basin and its outlet. It is to be regretted that no record of the log of this well has been preserved. An analysis made by Schweitzer in 1892[a] is here given:

Analysis of water of artesian well at Nevada, Vernon County.[b]

[Analyst, Paul Schweitzer, 1892.]

	Parts per million.		Parts per million.
Silica (SiO_2)	14	Sulphate radicle (SO_4)	53
Calcium (Ca)	80	Chlorine (Cl)	423
Magnesium (Mg)	33		1,252
Sodium (Na)	307		
Bicarbonate radicle (HCO_3)	342		

[a] Missouri Geol. Survey, vol. 3, 1892, p. 122.

[b] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

A number of deep nonflowing wells in this district have been sunk the search for oil or gas. Among them may be mentioned the dr well of the Nevada Gas, Oil and Asphalt Company, 9 miles south Nevada, at an elevation of 821 feet above tide. The writer is indebt to Mr. George A. Pierson for the following record:

Log of drill well of Nevada Gas, Oil and Asphalt Company, 9 miles south of Nev Vernon County.

	Thickness.	Dep
	Feet.	*Fe*
Des Moines (294 feet):		
Surface clay	4	
Sand rock	30	
Shale	20	
Sand rock	30	
Slate	6	
Coal	3	
Shale rock	18	
Flint; at 180 feet strong water rose within 80 feet of top; well cased with 10-inch casing	23	
Sand rock; at 230 feet strong water rose within 85 feet of the top	100	
Mississippian (413 feet):		
Limestone	53	
Shale; 8-inch casing to this point	60	
Limestone	100	
Water limestone	100	
Sandy limestone	100	
Devonian and Joachim limestone (200 feet):		
Soft sandstone (probably limestone)	100	
Fairly hard sandstone (probably limestone)	100	
St. Peter sandstone (100 feet):		
Fine sandstone	100	
Jefferson City limestone (175 feet):		
Hard sand limestone; at 1,092 feet water thrown out of pipe 30 feet high	175	
Roubidoux sandstone (60 feet):		
Hard sandstone	"	
Gasconade limestone (207 feet):		
Hard limestone		
White sand		
Limestone		
White sandy limestone		
Limestone; water strong at 1,300 feet		
White sandy, hard limestone		
Hard white sandstone		
Dark-brown limestone (drillers call this Trenton		
Sandstone, unaccounted for		

This record has been a very difficult one to summarize. Th the courtesy of the company the writer was allowed to examin of the samples contained in glass tubes, and he feels little dou some of the material described as sandstone in the log is lim It is very common for drillers to use the term sandstone for a s limestone. The correlations, while somewhat doubtful, as stat believed to be approximately correct and check fairly well wit more reliable data.

This company has just started another well west of Nevada NE. ¼ sec. 16, T. 35, R. 31. The altitude at the mouth of this 821 feet.

The water supply of Nevada is derived from 2 wells, 1,001 a feet deep. The altitude of the water station, obtained baromet is 900 feet. The water of the deeper well is strongly impre with sulphureted hydrogen and deposits a white precipit *Begatoria alba* around the outlet. The temperature was 67° F.

the air temperature was 69° F. The water stands 78 feet below the surface and is pumped into a large reservoir, from which it is distributed to the city. The water station is about 80 feet above the park where the flowing well previously described is located. The following log of the deeper well is furnished by Mr. J. P. Stevenson:

Log of city waterworks well, Nevada, Vernon County.

	Thickness.	Depth.
	Feet.	*Feet.*
Des Moines (170 feet):		
Drift	8	8
Sand rock	52	60
Sand shale	10	70
Trace of coal	3	73
Sand shale	48	121
Black slate	49	170
Mississippian (448 feet):		
Limestone	150	320
Sandstone	15	335
Limestone	60	395
Hard flint limestone	40	435
Lime rock	25	460
Slate	35	495
Lime rock	123	618
Devonian and Joachim limestone (157 feet):		
Gritty bastard limestone	20	638
Lime rock	22	660
Sandy bastard lime rock	35	695
Flint lime rock	40	735
Lime rock	40	775
St. Peter sandstone (43 feet):		
White sand	10	785
Lime rock	45	830
Sand	23	853
Flint	15	868
Jefferson City limestone (133 feet):		
Lime rock	32	900
Salt lime rock	30	930
Sandy lime rock	20	950
Blue lime rock	31	981
Unaccounted for	20	1,001

RICHARDS.

In the southwest corner of sec. 30, T. 36, R. 33, is a well owned by E. S. Weyand; depth, 650 feet; altitude, barometrically, 765 feet; flow, weak; casing, 6-inch; temperature of water, 62° F.; of air, 59° F.; date of completion, 1889; driller, John A. Young; surface formation, Cherokee shales. Like many others, this well was sunk during the oil excitement, and it was near enough to the Kansas oil fields to show some evidence of gas, which would burn for a short time, but which soon became exhausted. Now only a little gas comes up, intermittently, in small bubbles. There is a strong odor of sulphureted hydrogen and a thin white film is deposited around the outlet of the well. The owner informed the writer that before a rain storm the water becomes slightly milky in the trough. Washing one's hands in the water as it comes from the pipe also gives it a milky appearance—a peculiar phenomenon which may, perhaps, be explained by the breaking up of the gas bubbles. This water has a larger amount of sulphureted hydrogen than any other in the State, so far as known. It is stated that the water will rise in a pipe 15 feet above the surface.

SHELDON.

Six miles east of Sheldon, on the farm of L. C. Moore, in sec. 30, T. 34, R. 30, on the western slope of an anticlinal fold having a northeast-southwest trend, a well 17 feet deep was bored through the Graydon sandstone to the Mississippian. The water immediately rushed up, and a pipe was inserted through which it was conveyed to a tank. This is a very interesting example of the conditions favorable for artesian pressure. The limestone rocks of the Mississippian outcrop in strongly tilted ledges in the road not far away, running down the westerly slope of the anticline. The sandstone on the summit of the fold forms a catchment area through which the water penetrates to the Mississippian limestone or water table. When the reservoir is tapped low down on the fold, the water rises to the surface. The water of the Moore well is chalybeate and leaves a yellow deposit.

The anticline just referred to is one of a series of such folds that run with a northeast-southwest trend over a considerable area, and in many places the ridges outline these folds. East-west roads crossing these ridges show in the gullies the outcrops of the tilted sandstones, shales, and limestones on the slopes of the folds. The extension of these folds to the north has affected the course of the rivers, especially the Missouri.

In July, 1903, the Vernon Oil and Mining Company, of Sheldon, began drilling a well for oil and gas 4½ miles northeast of Sheldon, on the farm of Dr. C. B. Brand. This well was sunk to a depth of 1,306 feet, when work was stopped in October of the same year. The cost of drilling was about $2.25 per foot. The following is a log of this well, with correlations that are believed to be approximately correct:

Log of the Vernon Oil and Mining Company's well in the SE. ¼ SW. ¼ sec. 27, T. 34, R. 30, Vernon County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (20 feet):		
Soil	20	20
Des Moines (95 feet):		
Sandstone saturated with asphalt	25	45
Shale	30	75
Dark shale	40	115
Burlington limestone (235 feet):		
Coarse-grained crystalline limestone, some chert	210	325
Hard, compact crystalline limestone	25	350
Chouteau limestone (60 feet):		
Buff sandy limestone; water rose within 25 feet of surface	25	375
Buff sandy limestone, some flint	10	385
Buff sandy limestone	25	410
Hannibal sandstone and shale (75 feet):		
Brown sandstone, some shale	25	435
Bluish-white shale	50	485
Devonian (45 feet):		
Flint and compact limestone	45	530
St. Peter sandstone (30 feet):		
White sandstone; water came within 120 feet of top	10	540
Flint and limestone, with white rounded pebbles of sandstone	20	560
Jefferson City limestone (230 feet):		
White sandy limestone; probably siliceous limestone	230	790
Roubidoux sandstone (35 feet):		
Irregular sand grains, iron stained	35	825
Gasconade limestone (481 feet):		
Limestone, with occasional chert layers; at 1,250 feet some finely crystalline limestone, with soft gray shale	425	1,250
Record lost	56	1,306

STOTESBURY.

Just east of Stotesbury in the NE. ¼ NE. ¼ sec. 28, T. 37, R. 33, on the south bank of Osage River, a well was put down by the Missouri Oil and Development Company in August, 1901. It has flowed feebly ever since, except in very dry weather. The following log is given:

Log of well No. 1 of Missouri Oil and Development Company, near Stotesbury, Vernon County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pleistocene (9 feet):		
Soil	9	9
Des Moines (269 feet):		
"Soapstone"	20	29
Coal	3	32
"Soapstone"	13	45
"Soapstone" and blue shale	20	65
"Soapstone" and black sand	22	87
"Soapstone" and blue shale	3	90
Black sand and blue shale	30	120
Limestone	5	125
"Soapstone" and blue shale	12	137
Coal	3	140
Oil, sand, and shale	30	170
Slate and "soapstone"	35	205
Black and blue sandy shale and sandstone	20	225
"Soapstone" and shale	18	243
Limestone	2	245
Sandy shale	15	260
Fine-grained micaceous sand	5	265
Gray and black shale, with some sand	5	270
Micaceous carbonaceous shale	5	275
Carbonaceous sandy shale	3	278
Mississippian—Burlington limestone (67 feet):		
Cherty limestone	6	284
Same	1	285
Gray cherty limestone	5	290
Shaly limestone, some soapstone	5	295
Gray cherty limestone	50	345

Four miles west of Stotesbury, in a prospect hole for gas and oil, water rose and gently flowed over the surface.

WALKER.

Four miles northwest of Walker, on the farm of E. T. Litton, a well was sunk to a depth of 400 feet. The water obtained is strongly impregnated with sulphur, and the well has a rather strong flow, which has not materially decreased.

SOUTHWESTERN DISTRICT.

GENERAL ARTESIAN CONDITIONS.

The southwestern district includes an irregular area in the southwestern portion of the State, in Barry, Christian, Dent, Greene, Howell, Jasper, Laclede, Lawrence, McDonald, Newton, Ozark, Phelps, and Texas counties. The conditions in this district are in general rather unfavorable for strong artesian pressure, although there are several good wells. The country is much broken by folding, faulting, and fissuring, especially in the lead and zinc region. Several

wells are found along the slopes of the larger folds. The general dip of the rocks is toward the west and southwest. In southern Christian County the dip is to the southeast. As the richest zinc mines in the world are located in this district a great many drill holes have been made and careful records of many of them have been kept. Flowing wells are found at or near the following places: Comet and Corry, Lawrence County; Carl Junction, Jasper County; Neosho, Newton County; Tiff City, Lanagan, Noel, and Wanda, McDonald County; Ash Grove, Greene County; and in Christian County.

BARRY COUNTY.

EXETER.

Northwest of Exeter, Barry County, is a well owned by the St. Louis and San Francisco Railroad, and drilled by E. F. Stanley. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of St. Louis and San Francisco Railroad well near Exeter, Barry County.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil	65	[illegible]
Strata of lime and flint, alternating	230	[illegible]
Slate	23	[illegible]
Lime and flint	50	[illegible]
Sand rock, bearing water of a sulphur nature, but good for any purpose	44	[illegible]

CHRISTIAN COUNTY.

In Christian County, 15 miles south and east of Ozark, is a well owned by the New England Zinc Company. Depth, 225 feet; altitude, barometrically, 990 feet; casing, 10-inch; temperature of water, 58° F.; of air, 86° F.; flows feebly over a pipe 2 feet high; surface formation, near base of Jefferson City limestone. This well was sunk as a prospect hole for zinc by the New England Zinc Company and is located on the east side of the highway near Bull Creek. The water has a slight odor of sulphur, and it has deposited an iron precipitate in the pipe, which is corroded at numerous points. The rocks dip decidedly to the southwest for several miles. As far as the writer could learn this is the only flowing well in southern Missouri on the south side of the Ozarks. The water supply probably comes from some sandstone-bed in the Gasconade formation. No log could be obtained and no analysis of the water has ever been made.

DENT COUNTY.

SALEM.

Four miles southwest of Salem, Dent County, in sec. 3, T. 33, R. 6, is a well owned by Warren Bertrand and drilled by C. C. Gower. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Bertrand well near Salem, Dent County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soft sand, red	80	80
Gray lime, soft	60	140
Blue lime, medium soft	10	150
White flint, hard	2	152
Blue lime, soft	8	160

Seven miles south of Salem, in sec. 18, T. 33, R. 5, is a well owned by George Bullock and drilled by C. C. Gower. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Bullock well near Salem, Dent County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soft red clay	20	20
Soft red sandstone	75	95
Hard white lime	40	135
Hard gray flint	4	139
Rather soft white lime	18	157

West of Salem in sec. 13, T. 34, R. 6 is a well owned by W. L. Hogh and drilled by C. C. Gower. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Hogh well near Salem, Dent County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	4	4
Soft yellow clay	36	40
Blue flint, hard	5	45
Gray flint, hard	5	50
White flint, hard	5	55
Gray flint, hard	5	60
White flint, hard	9	69
Gray flint, hard	16	85

West of Salem, in sec. 13, T. 34, R. 6, is a well owned by Ge Stellman and drilled by C. C. Gower. The following log was recei from Messrs. M. L. Fuller and S. Sanford:

Log of Stellman well near Salem, Dent County.

	Thickness.	De
	Feet.	*F*
Clay, red	20	
Flint rock, hard, blue	2	
Clay, yellow	13	
Flint rock, hard, white	1	
Clay, yellow, soft	4	
Flint rock, hard, white	1	
Clay, yellow, soft	14	
Flint rock, hard	2	
Clay, red, soft	2	

One mile east of Salem, in sec. 18, T. 34, R. 5, is a well owned J. A. Murray and drilled by C. C. Gower. The following log received from Messrs. M. L. Fuller and S. Sanford.

Log of Murray well near Salem, Dent County.

	Thickness.	De
	Feet.	*F*
Yellow clay	10	
Yellow clay, with an occasional flint bowlder	45	

GREENE COUNTY.

ASH GROVE.

About 1878 Judge Ralph Walker, then of Ash Grove, sunk a pect hole 226 feet deep on the south line of sec. 28, T. 30, R the Corum land and kept a very careful record of the strata p through. The following log was furnished by him. This wel particularly good one, and it is unfortunate that it was not deeper.

Log of Walker drilled well, Ash Grove, Greene County.

	Thickness.
	Feet.
Burlington limestone (136 feet):	
Soil	
Coarse-grained gray limestone	
Buff colored rock (Chouteau-like layers), chert, and calcite	
Limestone and chert	
Coarse brown limestone, known as "yellow rock"	
Fine-grained limestone with ferruginous clay and calcite	
Limestone	
Light drab limestone, ferruginous chert	
Coarse-grained limestone, much chert and pyrite	
Mostly white chert, with some argillaceous matter	
White chert, shaly, drab-colored magnesian limestone	
Shaly, argillaceous, impalpable powder	

Log of Walker drilled well, Ash Grove, Greene County—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Chouteau limestone (43 feet):		
Greenish-yellow, coarser magnesian limestone	4	140
Buff-colored argillaceous limestone, little chert	3	143
Drab argillaceous magnesian limestone	16	159
Dark-drab magnesian limestone, much white chert	10	169
Shaly magnesian limestone, coarse grained, no chert	5	174
Gray magnesian limestone, calcite crystals, much chert	5	179
"Sac" limestone [a] (14 feet):		
Gray magnesian limestone, no chert	11	190
Bluish-gray magnesian limestone, with bluish-drab shale	3	193
"Eureka" shale [b] (23 feet):		
Blue slate with bituminous shale and chert	23	216
"King" limestone [b] (6 feet):		
Drab magnesian limestone, coarse grained, little shale, and ferruginous clay	6	222
Joachim limestone (4+feet):		
Drab magnesian limestone, marcasite crystals	2	224
Light-drab magnesian limestone, fine grained, no silica	2	226

[a] Missouri Geol. Survey, vol. 12, 1898, p. 74.
[b] Ibid., p. 67.

In 1891 the Pennsylvania Mining Company sunk a shaft near the railroad track, not far from the middle of section 28 and close to the city of Ash Grove. The following section is taken from Winslow's report on lead and zinc deposits,[a] the correlations for the summary being made by the writer, who also visited the shaft during the process of sinking. The Devonian was determined from the finding of shark's teeth, *Ptyctodus calceolus*.

Section of Pennsylvania Company's shaft at Ash Grove, Greene County.

	Thickness.	Depth.
	Feet.	*Feet.*
Burlington (180 feet):		
Surface débris	17	17
Limestone, white, crystalline, no chert; probably Burlington	23	40
Limestone, yellow, with clay pockets and perhaps some chert; close textured; an intercalated bed in the Burlington, frequently mistaken for Chouteau	40	80
Limestone, dark colored, coarsely granular	10	90
Limestone, light gray, finer textured	15	105
Limestone and chert in very thin layers, limestone fine grained and dense	75	180
Chouteau limestone (40 feet):		
Shale, drab, close textured, dense, slacks on exposure	40	220
Devonian (25 feet):		
Limestone, dark colored, coarsely granular, growing finer in texture and more arenaceous toward base, contains some pyrite	4	224
Quartzite, calamine near top, somewhat dark colored	6	230
Sandstone or quartzite, white	8	238
Shale, dark, calcareous, passing upward into the sandstone	3	241
Shale, almost black, arenaceous in lower half; much water flowed from stratum	4	245
Joachim limestone (25 feet):		
Magnesian limestone, light gray and porous; probably Silurian	5	250

In the spring of 1906 the Ash Grove White Lime Association drilled a well just northeast of their lime kilns at Ash Grove. At a depth of 260 feet a strong flow of pure water was struck, with a pressure sufficient to carry it 30 feet above the surface. No record of drillings could be obtained, but it is probable that the water came

[a] Missouri Geol. Survey, vol. 7, pt. 2, 1894, p. 628.

from the St. Peter sandstone. The well started in the Burlington. The following is the analysis of water from this well:

Analyses of water from well of Ash Grove White Lime Association, Ash Grove.

[Analyst, A. F. Shattuck, chief chemist, The Solvay Process Company, Detroit, Mich., December 5, 1905.]

Sanitary Analysis.	Parts per million.	Mineral Analysis.	Parts per million.
Total residue	181.8	Silica (SiO_2)	9.80
Loss on ignition	37.8	Oxide of iron and alumina ($Fe_2O_3+Al_2O_3$)	Traces.
Oxygen consumed	.4	Calcium (Ca)	39.16
Albuminoid ammonia	.056	Magnesium (Mg)	19.02
Free ammonia	.08	Sodium (Na)	2.87
Nitrites	0	Chlorine (Cl)	4.44
Nitrates	.09	Sulphate radicle (SO_4)	15.97
Turbidity. none.		Carbonate radicle (CO_3)	90.98
Sediment, none.			
Color, none.			
Odor, none			

The mineral constituents are probably combined as follows:

Hypothetical combination of minerals in water from well of Ash Grove White Lime Association, Ash Grove.

Silica (SiO_2)	9.80
Iron and alumina ($Fe_2O_3+Al_2O_3$)	Traces.
Calcium carbonate ($CaCO_3$)	94.64
Calcium sulphate ($CaSO_4$)	4.37
Magnesium carbonate ($MgCO_3$)	55.10
Magnesium sulphate ($MgSO_4$)	15.98
Salt (sodium chloride) (NaCl)	7.31

The water is slightly alkaline, as the analysis shows.

The carbonic acid was estimated by calculation from the remainder of the analysis, as the sample was not large enough to permit an accurate determination of it after the other determinations were completed. The carbonates are probably present as bicarbonates; that is, they are held in solution by an excess of carbonic acid over the amount necessary to form the normal carbonates.

SPRINGFIELD.

At Springfield, Greene County, there are three wells from which a record of 1,000 feet has been partially obtained. The logs of the three wells are as follows:

Log of Springfield Traction Company drill well, corner Phelps avenue and Main street Springfield, Greene County.

	Thickness.	Depth.
	Feet.	*Feet.*
Burlington (250 feet):		
Limestone, soft, cherty	50	50
Coarse-grained gray limestone, some chert	70	120
Limestone, soft, cherty, gray, and white	50	170
Limestone, dark yellowish drab, clayey	20	190
Chert, drab and white, compact and coarse (Chouteau?)	20	210
Limestone, gray and dark brown, little chert	40	250
Hannibal (30 feet):		
Shale, dark drab; plastic clay	30	280
Louisiana (20 feet):		
Limestone, very compact, dense, dark gray, small quantity white knife-blade chert	20	300
Devonian (40 feet):		
Sandstone, well cemented, fine grained, white	10	310
Limestone, compact, white or light gray, some gray chert and iron stains	10	320
Limestone, compact, bluish gray, some iron stains; probably same as last; free from chert	10	330
Same as last, but with peculiar brownish-gray tinge, apparently more magnesian	10	340
Joachim limestone (60 feet):		
Limestone, rather soft, white, earthy, free from chert, some iron stains	10	350
Limestone, cherty, yellowish, with light-gray sandstone and calcareous cement; iron stains numerous	10	360
Limestone, compact, light gray, few rounded quartz grains	10	370
Limestone, dark gray, dense, with a siliceous appearance, inclosing a few rounded grains of quartz; iron stain	10	380
Missing	20	400
St. Peter sandstone? (35 feet):		
Sandstone, light color to grayish yellow, fine grained, with calcareous cement; iron stains	20	420
Limestone, light gray, siliceous	10	430
Sandstone, fine grained, light colored	5	435

No record is available from 435 to 617 feet, where the following log begins:

Log of gas company well, Springfield, Greene County.[a]

[Record first preserved at 617 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Limestone, light gray, with little white chert	.....	617
Limestone, fine grained, brownish gray, crystalline, a little white chert	3	620
Limestone, compact, gray; bluish-white chert; iron stains	10	630
Limestone, compact, earthy, nearly white, free from chert; little iron stain	10	640
Limestone, dark, grayish, crystalline, with white chert	10	650
Limestone, hard, white, earthy to brownish gray, crystalline; little iron stain	10	660
Similar, with white conchoidal chert, some vein quartz, and a small quantity of pink limestone	12	672
Limestone, dark gray, compact, containing rounded grains of quartz and a little chert	8	680
Limestone, gray, crystalline, with numerous rounded quartz grains and some chert	10	690
Sandstone, yellowish gray, with some calcareous matter and iron oxide	5	695
Limestone, finely crystalline, gray, chert partly colitic, and quartz grains	5	700
Record missing	127	827

[a] Jefferson City limestone, Roubidoux sandstone, and Gasconade limestone constitute this log, but they can not be correlated.

Log of Anheuser-Busch cold-storage well, Springfield, Greene County.

[Record first preserved at 830 feet.]

	Thickness.	Depth.
	Feet.	*Feet.*
Limestone, light gray, siliceous, with small proportion of iron oxide; mainly chert, part of which is oolitic		[illegible]
Limestone, light gray, less siliceous than above, and slightly dolomitic, with iron oxide and galena; cherty portion partly oolitic	5	[illegible]
Dolomite, gray, siliceous	15	[illegible]
Limestone, dolomitic, with iron oxide	10	[illegible]
Limestone, light gray to nearly white, fine grained; no oxide	5	[illegible]
Dolomite, fine grained, gray, siliceous, with a little iron oxide	3	[illegible]
Chert, nearly pure white to light gray, with some iron-oxide stains	13	[illegible]
Limestone, light colored, finely granular, free from chert; some iron oxide	12	[illegible]
Dolomite, dark-gray, rather finely crystalline, with a compact white chert resembling Burlington chert; iron-oxide stains	15	[illegible]
Limestone, light colored, with chert and iron stains	10	[illegible]
Limestone, light colored, nearly white and comparatively pure; iron stains	10	[illegible]
Limestone, fine grained, crystalline, gray, white calcite crystals, and pink dolomite; iron stains	5	[illegible]
Limestone, compact to crystalline, with chert and some iron stains	65	1,[illegible]

The well of the Springfield Traction Company was put down in the summer of 1902 in order to supply water for the boilers of the power house. The drillings were carefully watched by the writer. A good flow was obtained from the St. Peter sandstone, but the water was apparently impregnated with other water and very hard in consequence. The 35 feet of sandstone at 400 feet is, without doubt, the St. Peter sandstone, and is made up of rounded, waterworn quartz grains, slightly iron-stained, and loosely coherent. It is greatly to be regretted that complete records of the gas company and cold-storage wells are not obtainable.

About 1870 the St. Louis and San Francisco Railroad sunk a deep well for water at the car shops, north of Commercial street and Washington avenue, in what was then North Springfield. The drill record was not made public for many years. It is probable that the "sandstone" encountered from 610 to 645 feet in this well was a siliceous limestone. The writer had no opportunity to see the drillings, which were not preserved, but so many instances have occurred in which a limestone of this character has been mistaken for sandstone by the driller that this inference seems justifiable.

The water obtained from this well was clear and fine, though hard, and the temperature at the bottom of the well was 60° F. The well is situated on the crest of the great divide or watershed of the Ozarks, water to the north flowing into Sac, Osage, and Missouri rivers, and to the south into Wilson Creek, James, White, and Mississippi rivers. For this reason the water level is deep, being 225 feet. Considerable water was encountered at a depth of 325 feet, evidently from the "Phelps" sandstone. At 406 feet, in the St. Peter sandstone, the water was tested by pumping 500 gallons per hour, which lowered it

50 feet. More water was struck at 540 feet. At 610 feet, in the Roubidoux standstone, 750 gallons per hour were pumped without lowering the level.

The following is the log of this well:

Log of well at car shops, Springfield, Greene County.

	Thickness.		Depth.	
	Ft.	*in.*	*Ft.*	*in.*
Burlington (250 feet):				
Soil and limestone	35	.0	35	.0
Gray limestone	118	.0	153	.0
Flint and limestone	62	.0	215	.0
Limestone	35	.0	250	.0
Chouteau limestone (47 feet):				
Soft slate or soapstone	30	.0	280	.0
Gray limestone	17	.0	297	.0
Devonian ("Phelps" sandstone[a]) (4 feet):				
Sand rock	4	.0	301	.0
Devonian ("Sac" limestone[a]) (29 feet):				
Gray limestone	17	.0	318	.0
Flint, limestone with pyrites	12	.0	330	.0
Devonian ("King" limestone[a]) (6 feet):				
Light-gray limestone	6	.0	336	.0
Joachim limestone (54 feet):				
Flint and limestone	4	.0	340	.0
Gray limestone	7	.0	347	.0
White gritty limestone	25	.0	372	.0
Fine limestone	3	.0	375	.0
Coarse limestone	15	.0	390	.0
St. Peter sandstone? (16 feet):				
Porous sandstone	8	.0	398	.0
Limestone and some sand	8	.0	406	.0
Jefferson City limestone (126 feet):				
Bluish-brown limestone	29	.0	435	.0
Fine flinty limestone	77	.0	512	.0
Fine sand	10	.0	522	.0
Fine gray limestone	10	.0	532	.0
Roubidoux sandstone (55 feet):				
Very fine sand rock	55	.0	587	.0
Gasconade formation (138 feet):				
Brown limestone	5	.0	592	.0
Flinty siliceous rock	8	.0	600	.0
Very fine white sand rock	10	.0	610	.0
Finer sand	10	.0	620	.0
Sand	25	.0	645	.0
Brownish-gray limestone and flint	33	.0	678	.0
Reddish-brown limestone	12	.0	690	.0
Gray limestone and white flint	8	.0	698	.0
Fine white sand, sharp grit	22	.10	720	.10

[a] Missouri Geol. Survey, vol. 12, 1898, p. 67.

About 1888 the Frick Ice Company sunk several wells near Phelps avenue and Summit street. The water obtained was hard. The following is the log of one of the wells:

Log of well of old Frick ice factory, Springfield, Greene County.

	Thickness.	Depth.
	Feet.	*Feet.*
Coarse-grained gray limestone	100	100
White flint and gray limestone	40	140
Fine-grained limestone	40	180
Light gray argillaceous limestone	144	324
Light-gray fine limestone	16	340
Hard, fine-grained, shaly buff limestone	5	345
Fine-grained argillaceous limestone	27	372
Light-gray limestone	34	406
Fine white magnesian limestone	50	456

HOWELL COUNTY.

WEST PLAINS.

Three miles southwest of West Plains, Howell County, in sec. 35, T. 24, R. 8, is a well owned by the Frisco Ore Mining Company. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of well at West Plains, Howell County.

	Thickness.	Depth.
	Feet.	*Feet*
Red or yellow clay and chert, commonly known as Boone chert	60	60
Dolomite of irregular strata, carrying some iron ore all through from top to bottom	340	400

JASPER COUNTY.

CARL JUNCTION.

Three miles north of Carl Junction, near the Kansas City Southern Railway, in sec. 19, T. 29, R. 33, is a well on land owned by R. H. Crain, of Carthage. Three holes were drilled; the first two stopped flowing when the third was put down. These wells were sunk in 1900 to a depth of about 200 feet each. They are cased with 5⅝-inch casing to bottom. They passed through alternating beds of limestone and flint all the way down. No log was kept, but the drilling was all the way in Burlington limestone.

The third well has flowed continuously since it was first put down, the water rising 3 feet above the ground and flowing over the pipe. The water is clear, cold, and hard. The drilling was done by Mr. Kilgore, of Webb City.

CARTERVILLE.

Mr. W. C. Glenn, superintendent of the American Lead and Zinc Smelting Company, furnishes the following data in regard to a well, 799 feet deep, sunk on the company's land, at Carterville, Jasper County, in 1891. The principal vein of water was found at 700 feet, in sandy rock, and the water rises within 115 feet of the surface. It is used for boiler and drinking purposes. The drilling cost $1.10 per foot. No log was kept, but the following analysis of the water was obtained:

Analysis of water from deep well of the American Lead and Zinc Smelting Company, Carterville, Jasper County.[a]

	Parts per million.		Parts per million
Silica (SiO_2)	11	Bicarbonate radicle (HCO_3)	254
Iron (Fe)	.08	Sulphate radicle (SO_4)	1.2
Aluminum (Al)	.11	Chlorine (Cl)	5
Calcium (Ca)	53		355.69
Magnesium (Mg)	7.3		
Sodium (Na)	24	Total residue on evaporation	263.5

[a] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

CARTHAGE.

One of the deepest and most important wells in the southern half of the State is that at the Harrington dairy, near Carthage, at an elevation of 955 feet. This well is owned by Charles O. Harrington, proprietor of the Harrington Hotel. It was drilled, in 1890, to a depth of 2,005 feet, with an 8-inch bore. So far as known this is one of the four wells in the State, outside of the granite area, that reaches the crystalline rocks. Water is obtained by pumping, and is used for domestic purposes and for the dairy. It is slightly hard, clear, pure, and cold. The cost of this well was $4,000, and $1,000 more was expended for pump and tanks.

Log of Harrington deep well, near Carthage, Jasper County.

	Thickness.	Depth.
	Feet.	*Feet.*
Burlington limestone (355 feet):		
Soil and clay with chert fragments	15	15
Chert, buff and bluish white, somewhat coarse grained	15	30
Limestone, gray and white, with layers of chert and with 10 to 15 per cent magnesia	135	165
Chert, compact, white and buff colored, little limestone in lower half	80	245
Chert and limestone, white and drab, two-thirds chert	110	355
Chouteau (15 feet):		
Limestone, shaly, with some chert	15	370
Hannibal (15 feet):		
Shale, light drab and yellow	15	385
Devonian (65 feet):		
Limestone, grayish-brown, siliceous, cherty and sandy (rounded grains of white quartz)	65	450
Joachim limestone (50 feet):		
Dark-gray silico-magnesian limestone, with little chert (5 per cent)	50	500
St. Peter sandstone (85 feet):		
White sandstone, small rounded grains of quartz	60	560
Sandstone, some chert and siliceous gray limestone	25	585
"Potosi" and Saratogan (910 feet):		
Dark-gray magnesian limestone, cherty	15	600
Gray limestone with chert containing small sand grains	165	765
Fine-grained crystalline white limestone	55	820
Same, with a little chert and considerable brownish-yellow material	100	920
Similar, but with more chert and limestone and less brown material	80	1,000
Magnesian limestone	675	1,675
Magnesian limestone, slate-colored, clayey	75	1,750
Archean (255 feet):		
Fine dark-reddish porphyry grains with quartz sand	200	1,950
Same, darker and coarser, with light-colored dolomitic limestone and sand	55	2,005

CHITWOOD.

Mr. H. O. Ballard furnished the accompanying log of a deep well on the United Zinc Company's land at Chitwood, near Joplin, in sec. 32, T. 28, R. 33, on lot 48. This well has a 6-inch bore and was drilled to a depth of 800 feet. Water rises within 100 feet of the surface, and pumping does not materially affect its level. The water is used for boiler and drinking purposes. The cost of drilling was $800.

Log of deep well of United Zinc Company, Chitwood, Jasper County.

	Thickness.	Depth.
	Feet.	*Feet.*
Hardpan	18	18
Blue chert	27	45
Limestone and chert	35	80
Limestone	95	175
White chert	25	200
Blue chert and limestone	40	240
Shale	10	250
Blue chert and limestone	16	266
Shale	6	272
Chert	73	345
Limestone	5	350
Green selvage	15	365
Limestone and chert	10	375
Blue chert	3	378
Limestone	22	400
Chert	8	408
Limestone	123	531
Limestone and chert	4	535
Same	70	605
Limestone	4	609
Limestone and chert	31	640
Limestone	5	645
Limestone and chert	60	705
Limestone	95	800

DUENWEG.

Two miles northwest of Duenweg, Jasper County, is a well owned by S. D. Mitchell and drilled by S. N. Smith. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Mitchell well near Duenweg, Jasper County.

	Thickness.	Depth.
	Feet.	*Feet.*
Cement	13	13
Lime and chert	32	45
Chert, jack shines	5	50
Chert and lime	140	190
Chert, jack shines	10	200
Chert and lime	150	350
Coarse gray lime	150	500
Lime, black	155	655

JOPLIN.

The Missouri Lead and Zinc Company drilled a well in Joplin near the center of the NE. ¼ SW. ¼, sec. 11, T. 27, R. 33, at an elevation of about 1,018 feet above sea level. This well was drilled by Bailey & Waugh, and the following data were furnished by Mr. H. R. Conklin:

Log of well of Missouri Lead and Zinc Company, Joplin, Jasper County.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay and flint bow' lers	12	12
Lime	173	185
Flint	103	288
Lime	177	465
Lime and flint with very few shines of jack	5	470
Lime	20	490
Lime, flint, and sandstone	327	817
Flint, with very few jack shines	3	820
Siliceous limestone	140	960
White sandstone	10	970
Siliceous limestone	417	1,387

At 940 feet drilling was suspended and a pump placed in well 151 feet below the surface. The water level was 107.5 feet below the surface; capacity, 39 gallons per minute, and 35.3 gallons per minute after pumping twenty-three hours.

When the drill reached a depth of 1,387 feet the pump was again started. The water then rose within 110 feet of the surface; the capacity was 96½ gallons per minute after pumping one-half hour, 68 gallons per minute after pumping nine hours, and 68 gallons per minute after pumping twenty-three hours. In both tests the pump discharged all water furnished by the well due to the head pumped off, the pump being kept on air during the test. In November, 1903, the pump was lengthened to 211 feet. The water stood at a depth of 110 feet; the pump ran to a capacity of 125 gallons per minute without any indication of going on air.

The hole was drilled 13 inches in diameter to 400 feet, and cased to that depth with 10⅝-inch (inside) casing. From 400 to 1,105 feet the hole was drilled 8¼ inches, and from 1,105 feet to 1,387 feet 6¼ inches in diameter. All ground below the first 12 feet was hard enough to stand without caving.

The following are some analyses of the water from this well:

Analyses of water from well of Missouri Lead and Zinc Company, Joplin, Jasper County.[a]

ANALYSES AT TIME OF DRILLING.

[Analyst, Cleveland & Millar Analytical Laboratory.]

FIRST PUMPING, 940 FEET.

	Parts per million.
Silica (SiO_2)	14
Iron (Fe)	.83
Calcium (Ca)	44
Magnesium (Mg)	22
Sodium (Na)	23
Bicarbonate radicle (HCO_3)	272
Sulphate radicle (SO_4)	13
Chlorine (Cl)	10
	398.83
Residue on evaporation	263

SECOND PUMPING, 1,387 FEET.

	Parts per million.
Silica (SiO_2)	10
Iron (Fe)	.90
Alumina (Al)	.48
Calcium (Ca)	37
Magnesium (Mg)	17
Sodium (Na)	23
Bicarbonate radicle (HCO_3)	224
Sulphate radicle (SO_4)	14
Chlorine (Cl)	12
	338.38

ANALYSIS OF WATER TAKEN DECEMBER 7, 1903, FROM A TAP AT POWER HOUSE.

[Analyst, C. V. Miller.]

	Parts per million.
Silica (SiO_2)	12
Iron (Fe)	1.7
Calcium (Ca)	34
Magnesium (Mg)	14
Sodium (Na)	7.7
Bicarbonate radicle (HCO_3)	168
Sulphate radicle (SO_4)	16
Chlorine (Cl)	7
	260.4

[a] Expressed by analysts in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

ANALYSIS OF WATER TAKEN MAY, 1904.

[Analyst, J. H. Parsons Chemical Company.]

	Parts per million.		Parts per million.
Silica (SiO_2)	9.9	Chlorine (Cl)	8.8
Calcium (Ca)	41		
Magnesium (Mg)	18		175.7
Carbonate radicle (CO_3)	98		

The well pump is a Cornish-style lift pump, with barrel 7¾ inches in diameter, stroke 5 feet, operated by electric motor. Distribution system, 4-inch cast-iron pipe mains. Emergency steam pump, 14 by 8½ by 10 inches, duplex, supplied by reservoir of 1,000,000 gallons capacity, always ready for operation. Usual pressure, 40 to 80 pounds; fire pressure to be 100 pounds. In ordinary operation the well pump delivers water direct to the mains and the pressure is equalized by a pressure tank 36 by 7 feet in diameter, containing an air cushion.

The Freeman well, near Fourteenth and Joplin streets, Joplin, was drilled in 1901, to a depth of 908 feet, 400 feet being cased with 6⅝-inch casing and the remaining 508 feet with 5⅝-inch casing. Strong flows were obtained at depths of 815, 860, 875, and 900 feet. The water, which rises within 120 feet of the surface, is soft and contains a little sulphur. It is used for the boilers of the Freeman Foundry. The cost of the well was $2,000.

A strong odor of gas was noticed with the first flow of water, at 815 feet, and continued. When this depth was reached, seepage water rose in the case to 80 feet below the surface, but was easily bailed out. When the 815-foot flow was struck, the surface of the water in the well dropped to a depth of 119½ feet, where it has remained ever since. Neither compressed air nor bailing lowers this level, and the removal of 300,000 gallons in twenty-four hours has had no effect. The well is now pumped at the rate of 20,000 gallons in twenty-four hours. The temperature of the water is 65° F.

The following is an analysis of water taken from the 815-foot level:

Analysis of water from Freeman Foundry deep well, Joplin, Jasper County.[a]

[Analysts, Cleveland & Millar.]

	Parts per million.		Parts per million.
Silica (SiO_2)	7.2	Potassium (K)	Trace.
Iron and alumina oxides ($Fe_2O_3+Al_2O_3$)	.4	Bicarbonate radicle (HCO_3)	254
Calcium (Ca)	53	Sulphate radicle (SO_4)	35
Magnesium (Mg)	16	Chlorine (Cl)	7.0
Sodium (Na)	26		398.6

[a] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

The following is a more recent analysis of the same water, October, 1904:

Analysis of water from Freeman Foundry deep well, Joplin, Jasper County.[a]

[Analyst, Harrison Hale.]

	Parts per million.		Parts per million.
Silica (SiO_2)	35	Carbonate radicle (CO_3)	79
Iron and alumina oxides ($Al_2O_3+Fe_2O_3$)	9.7	Sulphate radicle (SO_4)	19
Calcium (Ca)	52	Chlorine (Cl)	5
Magnesium (Mg)	5	Organic	2.5
Sodium (Na)	3.5		210.7

Three and one-half miles southeast of Joplin, in sec. 7, T. 27, R. 32, is a well owned by the Rex Mining and Smelting Company and drilled by W. R. Burchell. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of well of Rex Mining and Smelting Company near Joplin, Jasper County.[a]

	Thickness.	Depth.
	Feet.	*Feet.*
Blue and white chert	230	230
Dark shale	5	235
Gray and white lime	472½	707½

Water was struck at about 60 feet.

One-fourth mile south of Joplin is a well owned by Tim McCarty and drilled by H. W. Atherton. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of McCarty well near Joplin, Jasper County.

	Thickness.	Depth.
	Feet.	*Feet.*
Red clay and chert	20	20
Dark lime and blue chert	35	55
Blue chert	5	60
Lime and white chert	40	100
Lime and chert; hard limy water	200	300

WEBB CITY.

At Webb City, Jasper County, the Missouri Zinc Fields Company sunk a well to the depth of 854 feet. The drilling was done by Crossman Brothers and was completed November 15, 1902. The altitude of the well is 940 feet. Strong flows of water were found at 795 and 845 feet, in limestone openings. Water rises within 100 feet of the surface. The cost of the well, piping, tanks, pumps, etc., was $2,150. The water is used for boiler and domestic purposes.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

The accompanying analysis of water from this well was made by Waring & Son, Webb City:

Analysis of water from well of Missouri Zinc Fields Company, Webb City, Jasper County.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	13	Sulphate radicle (SO_4)	4.8
Calcium (Ca)	52	Chlorine (Cl)	5.9
Magnesium (Mg)	18	Undetermined	7.7
Sodium (Na)	3.9		
Carbonate radicle (CO_3)	120		225.3

The following is the log of this well:

Log of well of Missouri Zinc Fields Company, Webb City, Jasper County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soapstone and slate sand bowlders	67	67
Limestone, shine of lead	9	76
Blue and white flint	1	77
Limestone and blue flint	45	122
Blue and white flint	24	146
Blue and white flint, zinc shines	14	160
Limestone bowlders	4	164
Blue and white flint, sand and spar ground, soft	41	205
Limestone and blue and white flint, hard	80	285
Slate and shale	1	286
Limestone and blue flint	60	346
Limestone	55	401
White sandy limestone	20	421
"Tiff" and spar	1	422
Gray limestone	68	490
Limestone and flint	12	502
Limestone and flint, dark; zinc shines	5	507
Limestone and white flint	98	605
Brown limestone and white and blue flint in strata	189	794
Opening	1	795
Sandy limestone	40	835
Blue and white limestone and "tiff"	9	844
Opening	1	845
Limestone	9	854

In a shaft, a short distance away, a stream yielding 1,000 gallons of water per minute was encountered. This water is highly charged with iron sulphate, which soon clogs the 6-inch pipe and which forms a cement binding the pebbles, etc., into a conglomerate where it flows out on the ground. The temperature is 64° F.

The Southwest Missouri Electric Railroad Company sunk a well to the depth of 826 feet, with an 8-inch bore, near its power plant at Webb City. The depth of the principal source of water is 815 feet and another vein was found at 250 feet. The water rises within 75 feet of the surface and has a temperature of 50° F. The well cost $2,000 for drilling, and an additional $500 for pumping machinery. The following analysis of the water is given, the analyst and date being unknown:

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

Analysis of water from well of Southwest Missouri Electric Railroad Company, Webb City, Jasper County.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	3.7	Sodium and potassium sulphates ($Na_2SO_4+K_2CO_4$)	24
Iron and aluminum oxides ($Fe_2O_3+Al_2O_3$)	5.0	Sodium and potassium chlorides ($NaCl+KCl$)	5.7
Calcium (Ca)	28		
Magnesium (Mg)	14		
Carbonate radicle (CO_3)	76		160.2
Sodium and potassium carbonates ($Na_2CO_3+K_2CO_3$)	3.8		

In 1899 the Center Creek Mining Company engaged H. B. Crossman, of Joplin, to sink a deep well in sec. 18, T. 29, R. 32. This well was drilled to a depth of 827 feet 6 inches and was cased with 8-inch casing for 315 feet. The principal source of water was found at 800 feet, in a sandy formation. Another vein was found at 500 feet. The level of the water in the well is 75 feet below the surface. The water is used for boiler and drinking purposes. The cost of drilling, with casing, was $2,300, with an additional $2,000 for pumping machinery.

Mr. W. C. Stewart, to whom the writer is indebted for this information, was secretary of the company, and states that the object of drilling was to get purer water for boilers and mines, and it was found to be so much better for drinking than the city water that four teams are engaged in hauling and selling it to various consumers. The accompanying analysis, furnished by Mr. Stewart, was made in December, 1899, by George Waring:

Partial analysis of water from deep well of Center Creek Mining Company, Webb City, Jasper County.[a]

	Parts per million.		Parts per million.
Calcium (Ca)	63	Chlorine (Cl)	3.4
Sodium (Na)	2.2		
Carbonate radicle (CO_3)	86		169.6
Sulphate radicle (SO_4)	15		

LACLEDE COUNTY.

LEBANON.

At Lebanon, Laclede County, in 1887, a well was sunk to a depth of 985 feet. The elevation of Lebanon is 1,265 feet. The first water was found at a depth of 135 feet in a bed of gravel overlain by clay.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

The force of the stream washed in the waterworn gravel and undermined the clay, thereby necessitating casing. At a depth of 427 feet the Roubidoux sandstone was reached and considerable water came in. The "Third" sandstone, or quartzite, was struck at the bottom of the well. From 500 to 600 feet the underground flow was so strong that drillings were obtained with great difficulty. From 680 to 960 feet drillings could be obtained only at a few points between openings. These cavernous openings are remarkable and indicate a strong underground current from the north. For further discussion of this subject the reader is referred to the writer's paper on the spring system of the Decaturville dome.[a] The first cavernous opening of 12 inches occurred at 615 feet; another at 633 feet; another of about 3 feet at 761 feet; another of 3 feet at 830 feet; one of 1 foot at 850 feet, and one of 1½ feet at 880 feet.

The water at present rises within 360 feet of the surface. It is very pure and is used for drinking, carbonating, and shipping, and also for boiler purposes. The well has a 6-inch bore and is cased to 135 feet. It is mainly used as a source of supply for the city of Lebanon. An analysis of the water is given on page 206. The following is the log of the well:

Log of city well at Lebanon, Laclede County.

	Thickness.	Depth.
	Feet.	*Feet.*
St. Peter sandstone (10 feet):		
Soil	5	5
Sandstone	5	10
Jefferson City limestone (417 feet):		
Bastard limestone with seams of clay and flint	155	165
Yellow cherty limestone	50	215
Bluish limestone	40	255
White flint	5	260
Brown limestone	5	265
White flint	5	270
Yellowish-brown limestone	20	290
White chert	20	310
Brown silic ous limestone	50	360
Yellow "cotton rock"	15	375
Grayish-white limestone	52	427
Roubidoux sandstone (32 feet):		
Quartzite (took twenty-four hours to cut)	2	429
Sandstone	30	459
Gasconade limestone (521 feet):		
"Cotton rock"	11	470
Coarse bluish limestone	15	485
Fine-grained brownish-yellow limestone	50	535
White flint	15	550
Compact yellowish limestone	20	570
Coarse limestone	10	580
"Cotton rock"	10	590
Clouded marble	20	610
Red ferruginous limestone	10	620
Opening	2	622
Gray and pink ferruginous limestone	50	672
Pink limestone	43	715
Coarse bluish limestone	25	740
Coarse light ferruginous limestone	10	750
"Cotton rock"	5	755
Pinkish limestone	6	761
Opening	3	764
Coarse dark limestone	35	799
Compact limestone	46	845

[a] Water-Sup. and Irr. Paper No. 110, U. S. Geol. Survey, 1905, pp. 113-125.

Log of city well at Lebanon, Laclede County—Continued.

	Thickness.	Depth.
Gasconade limestone—Continued.	*Feet.*	*Feet.*
Coarse ferruginous limestone	12	857
Hard limestone	10	867
Compact yellowish limestone	30	897
Coarse dark limestone	20	917
Compact yellowish-white limestone	8	925
"Cotton rock"	6	931
Limestone	42	973
Siliceous limestone, with pyrites	5	978
Bluish shale, possibly serpentine	2	980
Archean (5 feet):		
Quartzite	5	985

In 1890 a well 442 feet deep was sunk by the St. Louis and San Francisco Railroad at a distance of 60 feet from the city well. The following is the log of the railroad well:[a]

Log of well of St. Louis and San Francisco Railroad at Lebanon, Laclede County.

	Thickness.	Depth.
Jefferson City limestone (430 feet):	*Feet.*	*Feet.*
Soil and clay	30	30
Flint bowlders and clay	35	65
Limestone; first water at 85 feet	20	85
Limestone and chert	22	107
Limestone	24	131
Limestone and chert	19	150
Sandstone	18	168
Magnesian limestone	27	195
Chert bowlders	30	225
Limestone	5	230
Chert bowlders	20	250
Soft chert	40	290
Chert bowlders	35	325
Limestone	10	335
Limestone and chert	30	365
Limestone	22	387
Chert	20	407
Limestone	18	425
Chert	5	430
Roubidoux sandstone (12+ feet):		
Sandstone	12+	442+

LAWRENCE COUNTY.

AURORA.

At Aurora, Lawrence County, the deepest well, at present, is the drill well sunk by the Sphalerite Mining Company. This passed through an inclined ore body a part of the way, and the strata could not be correlated all the way down because of the secondary deposit of mineral. The well was put down in the summer of 1899. The following analysis was made by a Chicago chemist. The water was obtained after pumping for several hours.

[a] Acknowledgment is due to Mr. C. D. Purdon, engineer of maintenance of way of the Frisco System, for the logs of the city and railroad wells; also to Mr. M. W. Serl, of Lebanon, for many valuable notes on the city well and on the geology of Laclede County.

Analysis of water from well of Sphalerite Mining Company, Aurora, Lawrence County

	Parts per million.		Parts per million
Silica (SiO_2)	16	Carbonate radicle (CO_2)	[illegible]
Iron and alumina oxides (Fe_2O_3+ Al_2O_3)	16	Sulphate radicle (SO_4)	[illegible]
Calcium (Ca)	131	Chlorine (Cl)	[illegible]
Magnesium (Mg)	13		
Sodium (Na)	28		

The following is the log of the well:

Log of well of Sphalerite Mining Company, Aurora, Lawrence County.

	Thickness.	Depth.
	Feet.	*Feet.*
Burlington (356 feet):		
Soil	10	
Coarse gray limestone, some chert	115	
Flint, lime, and small calcite crystals	35	
Limestone and flint, with traces of marcasite, calcite, and copper and zinc ore	48	
Coarse brecciated limestone and flint (ore body), with much zinc and calcite	6	
Limestone and chert, with traces of calcite, marcasite, bitumen, and zinc ore	91	
Dolomitic limestone, chert, some zinc and calcite	13	
Shaly blue limestone	10	
Blue limestone, some chert and calcite	12	
Dark-gray limestone and chert, some zinc	8	
White flint, limestone, brecciated ore body, much zinc	2	
Gray limestone and flint	8	
Chouteau limestone (33 feet):		
Shaly dolomitic limestone	4	
Brecciated blue limestone, white flint, rich zinc	[illegible]	
Mainly blue limestone, chert	[illegible]	
Undifferentiated (107 feet):		
Shaly blue magnesian limestone	[illegible]	
Siliceous dolomitic limestone, some calcite and zinc	[illegible]	
Ore breccia, pink dolomite, blue limestone, and chert	[illegible]	
Gray limestone, some chert	[illegible]	
Gray dolomitic shaly limestone, trace of marcasite	[illegible]	
Dark-gray limestone, chert breccia, zinc, and pink dolomite	[illegible]	
Light-gray dolomitic limestone and chert	[illegible]	
Light-gray limestone	[illegible]	
Dolomitic limestone, cherty, some zinc	[illegible]	
Dolomitic limestone, fine grained, brecciated with zinc	[illegible]	
Dark-gray siliceous dolomitic limestone, white chert, some zinc	[illegible]	
Same, with some oolitic limestone at bottom	[illegible]	

COMET.

On the north bank of Sac River, just north of Comet post-[illegible] a well owned by Clate Hargroves. Depth, 170 feet; altitude [illegible] etrically, 890 feet; casing, 5⅝-inch; flow, carries water to a [illegible] 17 feet in a 3-inch pipe; date of completion, April, 1900; [illegible] M. C. Gothard, Dadeville, Mo.; cost, $170; surface formatio[illegible] lington limestone. This well was sunk by a Clinton mining [illegible] in prospecting for mineral. A flow of water was struck in w[illegible] at a depth of 166 feet. The log, which follows, was furnished [illegible] Gothard.

[a] Expressed by analyst in grains per gallon and hypothetical combinations [illegible] form and parts per million at United States Geological Survey.

Log of Hargroves's well, Comet, Lawrence County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	10	10
Coarse-grained gray limestone and flint	100	110
Blue shale	40	150
Devonian:		
Sac limestone[a]	10	160
Phelps sandstone[a] (water bearing)	10	170

[a] Missouri Geol. Survey, vol. 12, 1898, p. 74.

The water of this well is soft and pure.

CORRY.

Three small flowing wells are found near the Corry mines. They were shallow prospect holes for mineral. One of them is located on the farm of John Woody, 2½ miles southwest of Corry, and is 100 feet deep. Water flows feebly to the surface. The two others are located on the old Jim Boyd place, one-fourth of a mile due north of Corry, and each is about 100 feet deep.

PIERCE CITY.

Three and one-half miles northwest of Pierce City, Lawrence County, in sec. 7, T. 26, R. 28, is a well owned by J. L. Wight and drilled by Ira C. and W. P. Wight. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Wight well near Pierce City, Lawrence County.

	Thickness.	Depth.
	Feet.	*Feet.*
Flint bowlders mixed with clay	80	80
Sandstone, or rotten flint	37	117
Water	2	119
Ledge of flint	2	121
Crevice; stream of water	4	125
Solid flint	15	140

VERONA.

Five-eighths of a mile north of Verona, Lawrence County, in sec. 8, T. 26, R. 26, is a well owned by G. H. Ruggles and drilled by F. Lechner. The following log was received from Messrs. M. L. Fuller and S. Sanford.

Log of Ruggles well, Verona, Lawrence County.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface, rock, water on top of rock	43	43
Flint and lime, hard	37	80
Opening, large amount of water, some lead ore was found in drill cuttings	4	84
Flint and lime; some zinc ore appeared in cuttings	30	114
Flint, lime, and zinc	14	128
Light shale or "soapstone"	21	149
Flint and lime	4	153
Zinc ore in cuttings	14	167
Flint and lime; occasional shines of zinc ore, water very strong	41	208

M'DONALD COUNTY.

LANAGAN.

At the railway station in Lanagan, McDonald County, is owned by the Kansas City Southern Railway, of which the de about 600 feet; temperature of water, 58.1° F.; of air, 65.3° F. strong; surface formation, Burlington limestone. This is a strong flowing well, filling the tank for locomotives and supply neighboring hotel. The water is probably carried 30 feet ground. The record has been lost and the actual depth is unk The water is strongly charged with sulphureted hydrogen.

The Irvin Walker well is one-quarter of a mile southeast of La on the south side of the road leading to Pineville. Its depth feet; altitude, 865 feet; casing, 5⅝-inch, 18 feet; temperature of 53° F.; flow, 8 to 10 gallons per minute; date of completion, D ber, 1901; driller, Irvin Walker; surface formation, top of De shale. The following are analyses of this water:

Analysis of water from Walker well, Lanagan, McDonald County, January 17,

[Analyst, J. C. Draper.]

	Parts per million.		Parts pe
Calcium (Ca)	30	Organic matter	
Magnesium (Mg)	8.5		
Carbonate radicle (CO_3)	66		
Alkaline chlorides	106		

Analysis of water from Walker well, Lanagan, McDonald County, Mo

[Analyst, E. E. Ellis.]

	Parts per million.		Parts
Iron (Fe)	Trace.	Sulphate radicle (SO_4)	
Calcium (Ca)	77	Chlorine (Cl)	
Carbonate radicle (CO_3)	112	Turbidity	
Bicarbonate radicle (HCO_3)	136	Color	

NOEL.

On a hill one-fifth of a mile east of Noel, in sec. 14, T. 21, R a well owned by the Noel Improvement Company.[b] Depth, 8 altitude above tide, 865 feet; casing, 5⅝-inch, 6 feet; tempera water, 55° F.; flow; date of completion, January, 1903; driller Walker, Lanagan; surface formation, lower part of Burlington well was put down by a company of Noel citizens for the pu supplying the town with water, and for this reason the h drilled on the top of a hill 90 feet above the railway station.

[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form at the tion at United States Geological Survey.

[b] The writer is indebted to Mr. Irvin Walker, of Lanagan, for notes on this well and to W at Lanagan, and also for the privilege, accorded to Mr. Ellis, of examining a carefully kept ings from this well.

depth of 350 feet water was struck which rose rapidly under artesian pressure, escaping, according to Mr. Walker's statement, in a crevice of the rock, 16 feet below the surface. The following is the log of this well:

Log of deep well at Noel, McDonald County.

	Thickness.	Depth.
	Feet.	*Feet.*
Limestone, with layers of chert	95	95
Noncherty gray limestone	36	131
Soft brown shale, slightly carbonaceous	59	190
Compact gray limestone, with semiopaque chert	25	215
Gray and white limestone, with chert and fragments of black slate	115	330
Soft shaly gray magnesian limestone	15	345
Hard, compact gray limestone	5	350
Soft limestone	10	360
Hard compact limestone, with some earthy limestone	45	405
Similar limestone, with band of hard, black slaty shale	10	415
Hard, grayish-brown, finely crystalline limestone	5	420
Hard, compact brown shale	5	425
Gray limestone, generally earthy, with some slate	40	465
Fine-grained crystalline limestone, with much earthy limestone and no chert	177	642
Compact gray limestone, with a little chert	24	666
Fine-grained gray limestone, with hard black shale	99	765
Light-gray, finely crystalline limestone, with chert	10	775
Light-gray compact limestone	35	810
Similar limestone, with considerable semiopaque compact chert	70	880

SOUTHWEST CITY.

In Southwest City, McDonald County, is a well owned by Jacob Winters, and drilled by Sterner Brothers. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Winters well, Southwest City, McDonald County.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface and coarse rock	48	48
Blue flint and white quartz rock, with small deposits of coal at 74 and 78 feet	30	78
Light-gray rock	20	98
Dark-brown flint, with iron pyrite	12	110

Three miles west of Southwest City is a well owned and drilled by Levi Shinn. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Shinn well near Southwest City, McDonald County.

	Thickness.	Depth.
	Feet.	*Feet.*
Surface soil	10	10
Red clay	5	15
No entry	5	20
Flint	30	50
No entry	10	60
Red sticky clay	10	70
Bowlders	10	80
White and black red flint	15	95
White chalk rock	30	125

All of the above record is in the upper part of the Burlington.

TIFF CITY.

Three-fourths of a mile from Tiff City, in sec. 4, T. 23, R. 34, is a well owned by John Manning. Depth, 180 feet; casing, 5-inch, to rock; flow, weak; date of completion, June, 1900; driller, T. W. Hutchinson; cost, $180; surface formation, Burlington limestone. This well is situated in a valley, 300 feet from a small stream. The principal water was struck at a depth of 150 feet in crevices which opened in the rock. The flow has not varied since drilling, and the water, which is slightly charged with sulphureted hydrogen, is used for drinking.

WANDA.

In the SE. ¼ sec. 5, T. 24, R. 30, 1 mile northeast of Wanda post-office and about 7 miles south and east of Granby, there is a well on the land of W. R. Moore. Depth, 144 feet; altitude, barometrically, 1,086 feet; casing, 5⅝-inch, 20 feet; temperature of water, 57.2° F.; of air, 66.2° F.; flow, 42 cubic feet per minute; date of completion, 1901; surface formation, base of Burlington limestone. This well was sunk as a prospect hole for mineral. The flow has been strong from the first and has not varied.

Another well, which had also a strong artesian flow, was sunk near by at the same time. The stream of water is said to have come from cavernous openings in limestone. No log was kept, but the flow was probably from the base of the Devonian. The regional dip of the rocks in this district is toward the west.

NEWTON COUNTY.

DIAMOND.

Three and one-half miles west of Diamond, Newton County, in sec. 1, T. 26, R. 32, is a well owned by W. A. Parnell. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Parnell well near Diamond, Newton County.

WELL NO. 1.

	Thickness	Depth
	Feet.	Feet.
Surface, clay and flint bowlders	[illegible]	[illegible]
Limestone	[illegible]	[illegible]
Blue flint	[illegible]	[illegible]
Limestone	[illegible]	[illegible]
Blue flint	[illegible]	[illegible]
Limestone	[illegible]	[illegible]
Blue flint	[illegible]	[illegible]
Limestone	[illegible]	[illegible]
Blue flint	[illegible]	[illegible]
Limestone, water-plentiful at 140 feet	[illegible]	[illegible]
Limestone	[illegible]	[illegible]

In this vicinity there are four other wells. Their logs are as follows:

Log of wells near Diamond, Newton County.

WELL NO. 2.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, clay, and flint bowlders; water, running stream at 14 feet	14	14
Limestone	24	38
Blue flint	6	44
Limestone	52	96

WELL NO. 3.

Clay and flint bowlders; water, not so strong as in other wells, at 35 feet	35	35
Limestone	35	70

WELL NO. 4.

Soil, clay, hardpan	14	14
"Soapstone;" water pretty strong, soft, at 40 feet	26	40
Clean "tiff"	1	41
"Soapstone" and some black sand bowlders	54	95
"Burnt-looking limestone"	3	98
Brownish-yellow sand rock	6	104
Whitish flint rock	8	112
"Soapstone;" did not penetrate	36	148

WELL NO. 5.

Clay and hardpan	15	15
Clay and flint; water, soft	20	35
White flint	15	50
Clay and flint	45	95

The above wells are all in the Burlington limestone.

One and one-half miles north of Diamond, in sec. 31, T. 27, R. 32, is a well owned by Leathers Brothers and drilled by W. H. Leathers. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Leathers well near Diamond, Newton County.

	Thickness.	Depth.
	Feet.	*Feet.*
Red clay and flint	45	45
Lime and flint	83	128
White flint and zinc	2	130
Lime and flint	30	160
Soft white flint or water flint	50	210
Mississippi limestone	7	217

All of the above record is in the upper part of the Burlington.

MOUNT PLEASANT MILL.

The Granby Mining Company has drilled a deep well on the nor side of lot 15, in the SE. ¼ SW. ¼ sec. 31, T. 26, R. 30. The followi record was furnished by Mr. Elias Gatch, president of the compa

Log of well of Granby Mining Company, near Mount Pleasant Mill, Newton Coun

	Thickness.	Dep
	Feet.	*F*
Red ferruginous sandstone	21	
Blue clay, shale, and cherty flint	6	
Almost solid sheet of mundic, with very small vein of coal on top	6	
Mundic	2	
Black sand	3	
Blue clay and black sand	4	
Black sand	8	
Blue clay	16	
Gravelly flint	24	
Blue clay	6	
Flint	28	
Blue shale and flint	11	
Solid flint	7	
Mixed flint and lime, shines of blende	[a] 13	
Limestone	3	
Black flint	6	
Flint bowlders and clay	32	
Flint, with a little clay	42	
Opening containing mud	3	
Flint	12	
Lime and flint	11	
Limestone	14	
Siliceous magnesian limestone	28	
Lime and flint, flint largely predominating	82	
Limestone	8	
Limestone, with a little flint	25	
Limestone, with a band of white flint	90	
Limestone and flint, with some zinc	[illegible]	
Limestone	[illegible]	
Blue flint	[illegible]	
Blue flint and limestone	[illegible]	
Limestone	[illegible]	
Soft, shelly limestone	[illegible]	
Blue flint and clay	[illegible]	
Limestone	[illegible]	
Flint and limestone	[illegible]	
Flint and limestone	[illegible]	
White flint	[illegible]	
Limestone	[illegible]	
Limestone and flint, mostly flint	[illegible]	
Limestone, with a little flint	[illegible]	
Limestone	[illegible]	
Granular quartz	[illegible]	
Limestone, with strata of white clay	[illegible]	
Nearly pure limestone	[illegible]	
Limestone, with quartz in crevices	[illegible]	
Limestone, nearly pure	[illegible]	
Blue flint	[illegible]	
Nearly pure limestone	[illegible]	
Limestone, some flint, and dolomite crystals	[illegible]	
Limestone	[illegible]	
Hard flint	[illegible]	
Mainly limestone; water channel, ca. 1,014 feet; water rose nearly to surface	[illegible]	
Limestone	[illegible]	
Flint and limestone	[illegible]	
Limestone, with white sand	[illegible]	
Limestone and sandstone	[illegible]	
Granular limestone	[illegible]	
Limestone and sandstone	[illegible]	
Granular limestone	[illegible]	
Hard blue flint	[illegible]	
Granular limestone, with a little flint	[illegible]	
Limestone and flint	[illegible]	
Limestone	[illegible]	
Limestone, with black shale and a little black flint	[illegible]	
Limestone, with black shale and mundic	[illegible]	
Limestone	[illegible]	
Black sandstone and limestone	[illegible]	
Quartzite, lime, mundic, and tallow clay	[illegible]	
Nearly all limestone	[illegible]	

[a] Probably error in driller's log; should be 43 feet.

Log of well of Granby Mining Company, near Mount Pleasant Mill, etc.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Black flint (quartzite)	9	1,483
Calcium carbonate and quartzite	10	1,493
Very black limestone with odor of bitumen	38	1,531
Hard shale, denoting water channel	15	1,546
Limestone and black shale	16	1,562
Nearly all limestone	4	1,566
Limestone	8	1,574
Limestone and black shale	1	1,575
Nearly all limestone	5	1,580
Limestone and shale	21	1,601
Nearly all limestone	14	1,615
Limestone and shale	7	1,622

Hole abandoned and casing taken out.

NEOSHO.

There are several flowing wells near the city of Neosho. One is located on the east side of the railroad, two or three blocks south of the station. Depth, 300 feet; altitude, 1,018 feet; temperature of water, 58.1° F.; of air, 65.3° F.; flow, 1½ gallons per minute; date of completion, 1899; surface formation, Burlington limestone. This well was put down with the hope of obtaining mineral water, and was used for several years to supply a public bath house. The water is now used mainly for drinking purposes. It has a slight odor of sulphureted hydrogen. The following analysis was made by E. E. Ellis May 16, 1905:

Analysis of water of well at Neosho, Newton County.

	Parts per million.		Parts per million.
Iron (Fe)	Trace.	Sulphate radicle (SO_4)	35
Calcium (Ca)	80	Turbidity	None.
Bicarbonate radicle (HCO_3)	217	Color	None.

At the fish hatchery is a well put down by the United States Government. Its depth is 292 feet; altitude, 1,033 feet; casing, 5⅝-inch to 22 feet; temperature of water, 59° F.; flow, very weak, less than 1 gallon per minute; date of completion, 1899; surface formation, Burlington limestone. The following is the log of this well:

Log of fish-hatchery well, Neosho, Newton County.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil	10	10
Compact white and light-gray limestone, free from chert	48	58
Same, with compact white and gray chert	7	65
Dark-gray compact limestone, showing small calcite cleavage planes	8	73
Compact dark-gray chert, breaking with sharp edges, with a small mixture of compact gray and white limestone	85	158
Same, with slightly more limestone	28	186
Very hard and compact light-gray limestone, earthy-looking chert of same color	4	190
Dark brownish-black, rather hard shale, similar to that at Lanagan	22	212
Compact grayish-brown limestone, siliceous, finely crystalline	16	228
Same, with lighter and darker streaks, layers of chert in darker portion	64	292

The water has a slight odor and taste of sulphureted hydrogen, similar to that of the "Neosho" well. This well was drilled for the purpose of obtaining additional water for the fish hatchery, but work ceased when the water was found to be charged with sulphureted hydrogen, and at present the water is used only for drinking. The source of the water is probably at a depth of 150 to 160 feet, where openings were found. This well is probably all in the Burlington limestone.

OZARK COUNTY.

BAKERSFIELD.

One mile southwest of Bakersfield, Ozark County, in T. 22, R. 11, is a well owned by John Paris and drilled by W. L. Fowler. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Paris well near Bakersfield, Ozark County.

	Thickness.	Depth.
	Feet.	*Feet.*
Solid clay	10	10
"Soapstone"	125	135
"Copper"	6	141
Slate	15	156
Hard rock; "cuttings like ashes"	3	159
Black sandstone	2	161

PHELPS COUNTY.

EDGAR SPRINGS.

Two miles west of Edgar Springs, Phelps County, is a well owned by W. R. Denison and drilled by F. L. Cook. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Denison well near Edgar Springs, Phelps County.

	Thickness.	Depth.
	Feet.	*Feet.*
Dirt	40	40
Sandstone	108	148
Lime and flint	30	178

ROLLA.

The cores from a well drilled at Rolla in 1905 were furnished by Dr. George E. Ladd, director of the Missouri School of Mines, and from them the following record was obtained:

Log of well at Rolla, Phelps County.

	Thickness.	Depth.
	Feet.	*Feet.*
Jefferson City limestone (279 feet):		
Soil	25	25
Compact light-gray "cotton rock" (dolomite)	10	35
Same, trace of chert	5	40
Compact "cotton rock"	5	45
Same, with a little chert	5	50
Buff-colored fine-grained "cotton rock," some white chert	15	65
Gray splintery dolomite, some flint	20	85
Fine-grained buff-colored siliceous limestone, with white flint	5	90
Light-gray splintery limestone, some white flint	5	95
Light-gray splintery "cotton rock" (dolomite)	5	100
Fine-grained splintery siliceous magnesian limestone	5	105
Fine-grained white to gray cherty limestone	5	110
Fine-grained light-gray splintery siliceous dolomite	10	120
Fine-grained white dolomite, more compact	10	130
Fine-grained light-gray splintery dolomite	15	145
Coarser grained light-gray siliceous dolomite, granular, some chert, with little blue shale	25	170
Coarser grained gray siliceous dolomite, increase of chert and quartzite	15	185
Fine-grained dark-gray siliceous dolomite, some white chert and marcasite	20	205
Fine-grained dolomite, with some white chert and marcasite	19	224
Same, with dark-colored siliceous dolomite	5	229
Dark-gray siliceous dolomite and white chert	25	254
Mottled siliceous dolomite, some white chert and marcasite	25	279
Roubidoux sandstone (65 feet):		
Quartz sandstone, coarse, waterworn, little white chert and marcasite	20	299
Light-gray dolomite, with marcasite and white chert	10	309
Fine sandstone, with white siliceous dolomite and marcasite	5	314
Light-gray siliceous dolomite, with sandstone, white chert, and marcasite	20	334
Fine-grained white chert, with marcasite	5	339
White waterworn sand, white chert, and much marcasite	5	344
Gasconade limestone (256 feet):		
White to gray cherty quartzite, with marcasite	10	354
Gray siliceous dolomite, with some chert and marcasite	65	419
Light-gray fine-grained cherty quartzite sand, oolitic	15	434
Gray siliceous dolomite, with chert and more marcasite	39	473
Coarser blue and white chert, with some siliceous dolomite and grains of marcasite	5	478
Fine-grained gray siliceous dolomite, less white chert and marcasite	25	503
Fine-grained gray siliceous dolomite, with magnesian shale, white chert, and marcasite	10	513
Fine-grained siliceous dolomite, with cherty quartzite and some marcasite	15	528
Cherty siliceous dolomite and marcasite	65	593
Fine-grained sandy dolomite, chert, and much marcasite	5	598

Six miles southeast of Rolla, Phelps County, in sec. 28, T. 25, R. 7, is a well owned by J. W. Gower and drilled by C. C. Gower. The following log is furnished by Messrs. M. L. Fuller and S. Sanford:

Log of Gower well near Rolla, Phelps County.

	Thickness.	Depth.
	Feet.	*Feet.*
Dirt and clay	10	10
Red sand, soft	8	18
Flint rock, hard	4	22
Gray lime, soft	23	45
Blue lime, hard	10	55
White sand rock, soft	4	59
Blue lime, soft	6	65

WESTCOTT.

Two miles southeast of Westcott, Phelps County, in sec. 35, T. 33, R. 9, is a well owned and drilled by W. A. Corey. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Corey well near Westcott, Phelps County.

	Thickness.	Depth.
	Feet.	*Feet.*
Red clay	48	48
Flint mostly	32	80

TEXAS COUNTY.

PLATO.

In sec. 28, T. 33, R. 12, 3½ miles northwest of Plato, Texas County, is a well owned and drilled by F. L. Cook. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of Cook well, Plato, Texas County.

	Thickness.	Depth.
	Feet.	*Feet.*
Clay	60	60
Limestone	20	80
Sand rock	30	110
Lime and flint	36	146

ST. LOUIS BASIN DISTRICT.

GENERAL ARTESIAN CONDITIONS.

The well-defined St. Louis basin district includes a small area, which is made up of St. Louis, St. Charles, the northern portion of Jefferson, and the northeastern portion of Franklin counties. It lies mainly on the slope of an anticlinal ridge which extends from Plattin, Jefferson County, through Pacific, in the northeast corner of Franklin County, and, crossing Missouri River at a point between Labadie and St. Albans on the south side and passing through Klondike on the north side, in St. Charles County, continues northeastward through Warren County. This fold is well outlined along its course by the outcropping of the St. Peter sandstone, cross sections of which are finely shown in the bluffs along the river at Klondike and at Currelbaums Rock, on the south side of the river about 1 mile south of Becker, where the crumpled and disturbed condition of the strata is well exhibited. In this locality the Missouri, meeting the soft and somewhat crumpled St. Peter sandstone elevated by this fold, was enabled,

probably, to cut its way into another channel and continue along a new route to the Mississippi. The early channel of the Missouri probably passed by Labadie and Grays Summit into the Meramec, near Pacific.

The strata dip with considerable uniformity to the northeast and continue so for some distance into Illinois. Throughout the northern part of the State a general northeasterly dip from the Ozarks is characteristic of all the rocks but the Pennsylvanian series, which seem to have been deposited in several basins more or less independent of each other. In the district under discussion, however, this general dip is slightly interrupted by the course of the anticlinal fold above described.

A number of deep wells have been sunk in the St. Louis basin district. The records of only two have been carefully preserved, but these are so remarkable in their accuracy and completeness as to compensate, in a great degree, for the loss of data regarding the others.

This artesian district lies in a cone-shaped basin. On the north side is the Cap au Grès axis (briefly outlined by A. H. Worthen[a]), which brings the St. Peter sandstone to the surface in Cap au Grès Bluff, on Mississippi River. In describing this axis, Worthen says:

> It intersects the Mississippi bluffs immediately below the high bluff of St. Peter sandstone to which the name of Cap au Grès, or sandstone headland, was given by the French voyageurs, and, with a trend of E. 10° S., it intersects the bluffs of the Illinois about 2 miles below Monterey, crosses the bluffs on the eastern side of that stream about 5 miles above its mouth, and after intersecting an elbow of the river bluff for 3 or 4 miles is finally lost in the valley of the Mississippi.

It is stated by others that this axis within a short distance turns to the east and north and continues farther into Illinois.

The St. Peter sandstone outcrops in high bluffs between McLeans Creek and Sandy Creek, and at various points along this axis, which here takes a north by west course through Lincoln, Pike, and Ralls counties, forming what is known as the Lincoln Ridge. Broadhead states that the northernmost point at which this axis is noted in Missouri is near Newark, Knox County.

The geologic map of this region (Pl. I, p. 6) indicates that St. Louis is partially surrounded on the south, west, and north by two folds which show outcroppings of St. Peter sandstone. One of these is the Cap au Grès axis already described. The other, on the south, is the Pacific axis or anticline, extending from Crystal City and Plattin Rock, on the Mississippi, south of St. Louis, through Pacific and Klondike on the Missouri, and thence northward into Warren County. Within the area inclosed by these folds the cone-shaped St. Louis basin, having conditions highly favorable for artesian pressure,

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[a] Geology of Calhoun County: Geol. Survey Illinois, vol. 4, 1870, p. 2.

is located. East of St. Louis the rocks dip gently at the rate of 10 to 12 feet per mile.

There is little doubt that flowing wells might be obtained from the St. Peter sandstone along the Missouri and Mississippi valleys in the interior of this basin at an altitude not exceeding 450 feet. A summary of the thickness and depth of the St. Peter sandstone in this district is given in the following table.

Thickness and depth of St. Peter sandstone in St. Louis basin district.

Locality.	Thickness.	Depth.
	Feet.	*Feet.*
Housemans, near Brentwood		1,[illegible]
Clayton, St. Louis County		1,[illegible]
St. Charles		1,[illegible]
Insane Asylum well, St. Louis	133	1,[illegible]
Grone Brewery well, St. Louis		1,[illegible]
Belcher well, St. Louis	138	1,[illegible]
Belz Packing Company well, St. Louis		1,[illegible]
Godfrey, Monticello, Ill	100+	1,[illegible]
Granite City, Ill	125	1,[illegible]
Cahokia, near Monks Mound, Ill	125	1,[illegible]

The catchment basin for these wells is probably largely along the Pacific anticline.

FRANKLIN COUNTY.

LUEBBERING.

One hundred yards east of Luebbering, Franklin County, [illegible] 29, T. 41, R. 2 E., is a well owned by F. A. Pilliod and drilled by Widman. The following log was received from Messrs. M. L. [illegible] and S. Sanford:

Log of Pilliod well, Luebbering.

Red sand	[illegible]
Clay	[illegible]
Limestone	[illegible]
White sand	[illegible]

SULLIVAN.

In sec. 34, T. 42, R. 2, W., is a well on the farm of Thomas Rutherford; depth, 1,550 feet; altitude above tide, 641 feet; casing, 10-inch to 100 feet; 8-inch to 600 feet; 6-inch to bottom; temperature of water, 63.5° F.; of air, 87.8° F.; flow, 8 gallons per minute; dated completion, 1896; surface formation, base of Jefferson City limestone. This well does not strictly belong to the district in which it is placed, as it lies on the west side of the Pacific fold and probably derives its water directly from the Ozarks. It is described here for the sake of convenience. It was sunk in a series of interbedded hard sandstones and cherty limestones, and water is said to have come from a pure [illegible]

sandstone, the principal flow being from the bottom—1,550 feet. Water rose at first, it is said, to a height of 40 feet, but the pressure has since considerably decreased. It has been impossible to obtain the log of this well. Keyes[a] states that granite is said to have been encountered 1,100 feet from the surface in Franklin County, the reference being probably to this well. The water is good and contains some sulphur.

JEFFERSON COUNTY.

KIMMSWICK.

One-fourth of a mile north of Kimmswick, Jefferson County, in sec. 6, T. 42, R. 6, is a well owned by the Columbia Excursion Company and drilled by F. J. Miller. The following log was received from Messrs. M. L. Fuller and S. Sanford:

Log of well near Kimmswick, Jefferson County.

	Thickness.	Depth.
	Feet.	*Feet.*
Red clay (earth)	38	38
Black limestone	18	56
Yellow rock, soft	14	70
Blue-black slate or soapstone	25	95
White limestone	35	130
Blue flint	11	141

MADISON COUNTY, ILL.

GRANITE CITY.

The following log of a well at Granite City, Ill., was obtained by E. E. Ellis from George S. Reed, the driller. Altitude, about 435 feet.

Log of well at Granite City, Ill.

	Thickness.	Depth.
	Feet.	*Feet.*
Soft brown sandy loam	40	40
Coarse brown quicksand	50	90
Gravel	23	113
White limestone; well full of water	382	495
Soft gray slate	60	555
Hard brown limestone; water softer	30	585
Hard to softer gray sand rock; oil smell	63	648
White limestone; filled up with sulphur water	87	735
Hard gray sandy limestone	50	785
Shale with shells	15	800
Soft red and gray shale with shells	20	820
Soft dark shale	20	840
Medium gray limestone	50	890
Soft red and gray shale with shells	30	920
Medium pink magnesian limestone	55	975
Hard gray limestone; a little water	50	1,025
Soft green and gray shale	145	1,170
Hard pink magnesian limestone	330	1,500
Soft gray limeston; water at 1,580 feet	130	1,630
Very soft gray sandy limestone	15	1,645
Light-gray to white soft sandstone; at 1,650 feet the hole filled with mineral water which flowed from top	125	1,770
Yellowish lime rock	15+	1,785

[a] Missouri Geol. Survey, vol. 8, 1895, p. 334.

The St. Peter sandstone was struck at 1,650 feet. After going through 125 feet of this sandstone the drill penetrated 15 feet farther into yellowish Jefferson City limestone. The well was cased to 500 feet, and a vein of water found between 600 and 700 feet; cased again at 800 feet, and water found between 975 and 1,025 feet. It was next cased with 8½-inch casing to 1,035 feet. At 1,770 feet several efforts were made to case the water off, but all of them failed.

ST. CHARLES COUNTY.

ST. CHARLES.

At St. Charles a 6-inch well was sunk at Charles Shibi's brewery, 5½ Clay street, to a depth of 1,475 feet. Saline water with a temperature of 56° F. rose within 80 feet of the surface. The record of this well is lost, but it is stated that water was struck in a white sandstone. The brewery is situated about 100 feet above the river. The altitude at the Wabash Railway station at St. Charles is about 490 feet, which is probably 50 feet above the lower part of the city.

ST. CLAIR COUNTY, ILL.

MONKS MOUND.

Four miles northeast of East St. Louis, Ill., in Brook's pasture, near Monks Mound, St. Clair County, is a well owned by the Cahokia Development Company, of St. Louis, Mo. It was drilled by O. S. Willson and the record was furnished by S. L. Shellenberger, of Atoka, Ind. T. Altitude, about 450 feet; diameter of well, 12 inches to depth of 150 feet; date of completion, January, 1905.

Log of Cahokia Development Company's well near Monks Mound, Ill.

	Thickness.	Depth.
	Feet.	*Feet.*
Soil, sand and silt	70	70
Fine sand	20	90
Coarse quartz sand	10	100
Coarse sand, gravel and shells	80	180
Bluish clay and marl (water at 205 feet)	55	235
Bluish limestone and marl	15	250
Fine-grained white limestone	15	265
Compact limestone	70	335
Bluish fine-grained limestone (salt water at 365 feet)	10	345
White compact fine-grained limestone	10	355
Blue and grayish compact limestone	35	390
Rusty mottled limestone	30	420
Hard blue limestone	50	470
Fine-grained chocolate-colored limestone	15	485
Coarse bluish and grayish limestone	20	505
Reddish rusty-looking limestone	10	515
Grayish limestone	183	698
Bluish clay or marl	62	760
White limestone (salt water at 825 feet)	[a] 135	1,015
Reddish marl	30	1,045
Mottled limestone, clay, and marl	7	1,052
Grayish limestone	18	1,070

[a] Probably error in driller's record; should be 235 feet.

Log of Cahokia Development Company's well near Monks Mound, Ill.—Continued.

	Thickness.	Depth.
	Feet.	*Feet.*
Hard, gray and red limestone	25	1,095
Clay, "slate," or marl	10	1,105
Hard clay "slate"	30	1,135
Bluish limestone	35	1,170
Chocolate-colored limestone	25	1,195
Gray limestone	15	1,210
Fine-grained reddish limestone	15	1,225
Flinty dirt-colored limestone	5	1,230
Reddish-gray limestone	25	1,255
White flinty limestone	60	1,315
Granular dirt-colored limestone	20	1,335
Blue marly-looking shale (a little oil and gas at 1,490 feet)	155	1,490
Dirty grayish limestone	40	1,530
Fine-grained limestone of varying colors	445	1,975
White sand (well flowed slightly at 2,100 feet; sulphur water)	125	2,100

The first vein of water was struck at a depth of 205 feet. Salt water was obtained at 365 and 825 feet. At 1,490 feet a little oil and gas were encountered. When the well reached a depth of 2,100 feet a small stream flowed at the surface; the water came undoubtedly from the St. Peter sandstone. This record shows a gentle dip of the strata from Missouri eastward into Illinois.

ST. LOUIS COUNTY.

BRIDGETON.

Thirteen miles northwest of St. Louis, near Bridgeton, in T. 46, R. 6, is a well owned by C. D. Garnett and drilled by H. W. Steinsick. The following log was furnished by Messrs. M. L. Fuller and S. Sanford.

Log of Garnett well near Bridgeton, St Louis County.

	Thickness.	Depth.
	Feet.	*Feet.*
Alternate sands, limestones, shale and fire clay, all inclined to cave badly	260	260
Limestone, gray, hard; thin layers of clay	45	305
Limestone, light gray, very hard	10	315
Limestone, dark, brittle, arenaceous	115	430
Sandstone, dark gray, soft	70	500
Limestone, very dark, soft	18	518

ST. LOUIS.

At the corner of Main and O'Fallon streets, St. Louis, on the bank of Mississippi River is a well owned by the Belcher Water, Bath and Hotel Company. Depth, 2,199 feet; altitude above tide, 420 feet; temperature of water, 70° F.; flow, 75 gallons per minute; date of commencement, April, 1849; of completion, March 12, 1854; cost, $10,000; surface formation, Pennsylvanian.

The following is a portion of the description of the Belcher w given by Litton:[a]

Carbureted hydrogen was first perceived in passing the thin shale at a depth feet, and was found to increase in penetrating the soft shales at the depth of 6 and the red marl beneath, to augment in passing the shale at the depth of 885 fe to be evolved most abundantly in passing the bituminous marl at the depth of 9 This stratum of marl was found to be very bituminous and the borings when evolved much carbureted hydrogen, leaving a clay covered by the oxide of ir the depth of 1,090 feet the quantity of gas was found to diminish, and this dim continued to the depth of 1,135 feet. At the depth of 1,183 feet it began a increase, and became still more abundant at the depth of 1,222 feet. At the d 1,270 feet it diminished in quantity; but at 5 feet below it began again to i while at the depth of 1,301 feet its quantity was observed to diminish.

Sulphureted hydrogen was first observed at the depth of 1,510 feet, and th was then found to be strongly impregnated with it.

At the depth of 610 feet the water was first discovered to have a saline taste, 849 feet this property was found to be more marked, the water at that depth evaporation, leaving a residue of 1⅜ per cent of solid constituents. At the d 1,015 feet the quantity of these was found increased to 2¼ per cent. At 1,187 f percentage of salts in solution was found to have diminished, 1 pound of w evaporation leaving only 148 grams, but at the depth of 1,230 feet the percenta found to be about 3.

* * * * * *

The observations made during the sinking of the well showed that the main of water was obtained in the soft white sandstone at the depth of 1,515 feet; an experiments since made by Mr. Holm, by passing a tube to the depth at whi main supply of water was obtained, he thinks there is no water which rises to t face below this sandstone. This Saccharoid sandstone is very porous and is in the counties to the west and south of St. Louis, at which points the g the rocks is to the east and north.

* * * * * *

The ratio of the increase of the earth's temperature as we descend, deduced data furnished by the artesian well at St. Louis, does not agree with that from observations made at other artesian wells. The water as it flows from the refinery has a constant temperature, and according to my observation thermometer graduated to one-fifth of a degree, it is 23° C. = 73.4° F. The temperature of St. Louis, deduced from the observations of Doctor Eng continued daily during twenty-two years, is 55.22° F. = 12.9° C. Taking from which the water at the well comes to be 1,515 feet, this would give 1° F. for every 83.3 feet of descent; and for an increase of 1° C., a descent but for an increase of 1° C. requires, according to the observations at Gren of 104.6 feet; at Monsdorf, a descent of 97 feet; at Neusalswerk, a descent at Pregny, near Geneva, a descent of 97.3 feet.

* * * * * *

Five hundred grams of the water, to which had been added 1.984 grams p ate of soda, were evaporated in a platinum capsule to dryness, and heated gave for total weight of solid constituents 4.3955, in which was found 0.00 silica.

[a] Litton, A., Trans. St. Louis Acad. Sci., vol. 1, 1860, pp. 82-8

Analyses of water from Belcher well, St. Louis.[a]

[Analyst, A. Litton.]

No. 1.	Parts per million.	No. 2.	Parts per million.
).....	2.4	Silica (SiO_2).....	2.3
.....	4.5	Iron (Fe).....	4.4
a).....	495	Calcium (Ca).....	474
(Mg).....	180	Magnesium (Mg).....	172
a).....	2,472	Sodium (Na).....	2,365
(K).....	84	Potassium (K).....	81
radicle (CO_3).....	132	Carbonate radicle (CO_3).....	126
dicle (SO_4).....	576	Sulphate radicle (SO_4).....	551
l).....	4,706	Chlorine (Cl).....	4,500
ureted hydrogen (H_2S)	14		
ı dioxide (CO_2).....	55		8,275.7
	8,720.9		
evaporation.....	8,791		

minations of other gaseous constituents than carbonic acid and sulphureted were made for want of an accurate endiometer.

Log of Belcher well, St. Louis.[b]

	Thickness.	Depth.
s (628 feet):	*Feet.*	*Feet.*
e.....	27	27
.....	3	30
e.....	230	260
ck.....	15	275
e.....	75	350
.....	27	377
e.....	78	455
.....	3	458
e.....	37	495
.....	8	503
e.....	125	628
0 feet):		
.....	17	645
.....	30	675
.....	43	718
r, Trenton, and Black River (699 feet):		
.....	42	760
e.....	119	879
.....	67	946
us marl.....	20	966
.....	75	1,041
e.....	138	1,179
ck.....	60	1,239
e.....	133	1,372
.....	18	1,390
e.....	27	1,417
nestone, undifferentiated (782 feet):		
.....	47	1,464
e.....	38	1,502
ft sandstone.....	138	1,640
e with much iron.....	187	1,827
e with clay.....	192	2,019
e with lime and clay.....	136	2,155
ed.....	44	2,199

l by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form
· million at United States Geological Survey.
. Louis Acad. Sci., vol. 1, 1860, pl. 5.
Devonian.—E. M. S.

The company has recently built a fine large hotel and bath hou at the corner of Fourth street and Lucas avenue, to which point t water from this well has been piped. The water is aperient.

About 6 miles southeast of the Belcher well is the insane-asylu well, depth, 3,843½ feet; altitude above tide, 600 feet; temperature water (Broadhead), 105° F.; date of commencement, March 31, 186 date of completion, August 9, 1869; surface formation, Pennsylvania

The following log of this well was published by G. C. Broadhead 1878.[a] The work was superintended by Mr. C. W. Atkinson, who co lected specimens every few feet and carefully arranged them in box which were stored away in the asylum. He also filed with the coun clerk a section and record of the work.

Log of insane-asylum well, St. Louis.

	Thickness.	Dep
Clays of "Bluff" [Pleistocene] (40 feet):	*Feet.*	
Clay	40	
Pennsylvanian (80 feet):		
Tumbled masses of limestone	4	
Red clay	5	
Limestone	8	
Red clay	4	
Coal	5	
Fire clay	2	
Light-colored limestone; bottom of dry well	3	
Blue and drab clay, slightly calcareous	9	
Cherty limestone	6	
Dark and bluish-gray shales, slightly calcareous	[illegible]	
Cherty limestone	[illegible]	
Coal	[illegible]	
Light-blue clay	[illegible]	
Mississippian (570 feet):		
Hard cherty limestone, upper part fine grained, lower part coarse	[illegible]	
Blue shales	[illegible]	
Drab and gray limestone, generally hard and cherty	[illegible]	
Alternating limestone and shales	[illegible]	
Hard blue cherty limestone	[illegible]	
Very hard cherty, coarse bluish-gray to buff and drab cherty limestone	[illegible]	
Sandstone, very fine grained	[illegible]	
Mostly light gray or drab limestone; chert and limestone at 721 and 7[illegible] feet	[illegible]	
Chouteau group (93 feet):		
Red limestone	[illegible]	
Light-drab and gray limestone, some chert	[illegible]	
Argillaceous limestone	[illegible]	
Light-gray limestone, some chert	[illegible]	
Trenton, with Black River and Birdseye (421 feet):		
Mostly a light-gray or blue clay	[illegible]	
Dark clay	[illegible]	
Blue clay, alternating with thin limestone layers	[illegible]	
Blue and drab limestone, with probably some magnesian layers at 1,139 feet; creamy-colored limestone at 1,216 feet	[illegible]	
Light-blue cherty limestone; salt water at 1,220 feet	[illegible]	
Light-colored limestone	[illegible]	
Dark limestone	[illegible]	
First Magnesian limestone [Joachim] (148 feet):		
Light-drab cherty limestone	[illegible]	
Yellowish-gray limestone	[illegible]	
Dark limestone from 1,462 feet	[illegible]	
Light-colored limestone	[illegible]	
Saccharoidal sandstone [St. Peter] (133 feet):		
Mostly pure white sandstone, clear rounded grains, contains sulphur water; lower part on somewhat brown	[illegible]	
Second Magnesian limestone [Jefferson City] (517 feet):		
Buff-brown and drab cherty limestone	[illegible]	
Buff and drab cherty magnesian limestone	[illegible]	
Second sandstone [Roubidoux] (82 feet):		
Hard and mostly pure sandstone, with some limestone beds with chert; brown or reddish-gray	[illegible]	

[a] Trans. St. Louis Acad. Sci., vol. 3, No. 2, 1878, p. 2[illegible]

Log of insane-asylum well, St. Louis—Continued.

	Thickness.	Depth.
mesian limestone [Gasconade] (838 feet):		
tone and chert, drab, buff, and gray; chert beds probably include one-the series	*Feet.* 487	*Feet.* 2,671
rt from 2,671 to 2,735 feet; sand often abundant	172	2,843
sandstone with a little lime in upper part	37	2,880
tone, mostly free from chert and sand	142	3,022
lstone (98 feet):		
tone, dirty to blue and reddish-gray	98	3,120
agnesian limestone (384 feet):		
nagnesian slate	13	3,133
ish-drab or gray magnesian limestone, hard, with little sand; the r 66 feet is thin bedded and dirty reddish-gray, with some sandy beds.	371	3,504
andstone (54 feet):		
hard, thin-bedded sandstone, dark olive-gray in color, consisting of e and black grains	41	3,545
nd limestone	13	3,558
anite (285½ feet):		
sandstone near upper part, the lower mostly granite; the lower 40 is a hard red rock and is certainly powdered granite	285½	3,843½

dhead says:[a]

the borings began, the water in the well stood at 40 feet below the surface; at an 8 or 10 inch opening was struck and the water sank in the well to a depth et. Salt water was obtained at 1,220 feet. At 1,225 and 1,262 feet from the strong petroleum smell was recognized. Sulphur water was reached at 2,140 2,256 the water in the sand pump indicated 3 per cent of salt; at 2,957, 4½ at 3,293, 2 per cent; at 3,367, less than 2 per cent; at 3,384 feet, 3 per cent, w 3,545, 7 to 8 per cent.

ments with a Fahrenheit registering thermometer indicated the following:

Temperature at different depths in insane-asylum well, St. Louis.

Depth.	Temperature.	Depth.	Temperature.
Feet.	° *F.*	*Feet.*	° *F.*
3,127	106	3,604	105
3,129	107	3,641	104.5
3,264	106	3,728	105.5
3,376	106	3,800	105
3,473	105	3,837	105
3,533	105		

be regretted that no tests of temperature were made above these indicated

ng to the depth of 833 feet the drill was often observed to be highly magnetized, passing that depth no further influence was observed.

[a] Op. cit., p. 221.

At the corner of Forest Park boulevard and Vandeventer aven is a well owned by the Welle-Boettler Baking Company and drilled Ed. Meloy and A. W. Dickinson. The following log was furnis by Messrs. M. L. Fuller and S. Sanford:

Log of Welle-Boettler Baking Company well, St. Louis.

	Thickness.	D
	Feet.	
Filling	20	
Clay, gray, soft	20	
Sand and gravel	20	
Shaly limestone, gray, hard, little water	20	
Limestone, brown, soft	20	
Limestone, gray, hard, sharp	20	
Limestone, gray, soft	20	
Limestone	210	
Shale, light, soft	20	
Limestone, gray, hard	7	
Broken limestone and shale, gray, soft	15	
Limestone, gray, soft	10	
Limestone, gray, hard	55	
Limestone, gray, soft	60	
Limestone, gray, hard	35	
Limestone, light, hard	20	
Limestone, flint, gray, very hard	10	
Limestone, light gray, hard	15	
Shale, gray, soft [a]	7	
Limestone, gray, hard [a]	20	
Shale, dark red, soft, showing of oil [a]	20	
Limestone, gray, hard [a]	55	
Limestone and shale cave, gray, hard; hole caved badly	35	
Shale, black, soft; little oil	20	
Limestone, Trenton, brown, soft; little oil	30	

[a] 490 to 565 feet probably Kinderhook.

The St. Louis Transit Company sunk six deep wells at the of Park and Vandeventer avenues, four in 1899 and two in These varied from 500 to 800 feet in depth.[a] No records were served. One well was sunk to a depth of 500 feet, and in December, 1904, it was continued to 700 feet, when it was with 100 pounds of dynamite in the hope of obtaining gas. water from all these wells was strongly saline and impregnated sulphureted hydrogen. As it corroded the boilers, the wells abandoned. Water stands within 100 feet of the surface.

In 1895 the same company drilled a well at its station for power house, on the corner of Jefferson street and Geyer avenue depth of 1,400 feet. Strong sulphosaline water rose within feet of the surface.

The following analyses were furnished by Mr. Edward D. S the analyst and date being unknown.

[a] The writer is indebted to Messrs. Edward D. Smith and Charles F. Gregory for ing to these wells.

Analyses of water from wells of St. Louis Transit Company, Park and Vandeventer avenues, St. Louis.[a]

WELL BACK OF OFFICE.

	Parts per million.		Parts per million.
Silica (SiO_2)	18	Sulphate radicle (SO_4)	163
Iron and alumina oxides ($Fe_2O_3+Al_2O_3$)	5.2	Chlorine (Cl)	39
Calcium (Ca)	134		585.2
Magnesium (Mg)	28	Residue on evaporation	670
Sodium (Na)	25	Residue on ignition	530
Carbonate radicle (CO_3)	173		

WELL SOUTH OF RAILROAD TRACK.

	Parts per million.		Parts per million.
Silica (SiO_2)	12	Sulphate radicle (SO_4)	113
Iron and alumina oxides ($Fe_2O_3+Al_2O_3$)	4.4	Chlorine (Cl)	28
Calcium (Ca)	104		438.4
Magnesium (Mg)	19	Residue on evaporation	490
Sodium (Na)	20	Residue on ignition	400
Carbonate radicle (CO_3)	138		

DEEP WELL SOUTH OF RAILROAD TRACK.

	Parts per million.		Parts per million.
Silica (SiO_2)	13	Sulphate radicle (SO_4)	146
Iron and alumina oxides ($Fe_2O_3+Al_2O_3$)	Trace.	Chlorine (Cl)	32
Calcium (Ca)	118		497
Magnesium (Mg)	23	Residue on evaporation	533
Sodium (Na)	20	Residue on ignition	415
Carbonate radicle (CO_3)	145	Suspended matter	210

In 1903 the St. Louis Athletic Club sunk a well to the depth of 580 feet. No record was kept, and no analysis of the water has been made. It is stated that drilling stopped in a soft yellow sandstone. The water, which is saline, is pumped into the club's large swimming pool by a Worthington pump.

Numerous other wells have been sunk in St. Louis and vicinity to depths varying from 200 to 1,800 feet. In all cases saline water was obtained, and the largest supply came from the St. Peter sandstone at a depth of about 1,500 feet.

The Anheuser-Busch Brewing Company has two wells which have been abandoned, because of the corrosive action of the water on the boilers. At the Grone brewery, Twenty-third street and Clark avenue, water was found in the St. Peter sandstone at a depth of 1,450 feet. In June, 1904, the Belz Packing Company sunk a well on its property at 3600 South Broadway, and found water in the St. Peter sandstone at a depth of 1,500 feet.

[a] Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

One and one-half miles southwest of St. Louis, in block 2136, S Louis County, is a well owned by the Bambrick Construction Co pany and drilled by H. Steinsick. The following log was recei from Messrs. M. L. Fuller and S. Sanford:

Log of Bambrick Construction Company well, near St. Louis.

	Thickness.	De
	Feet.	
Dark-gray shaly oolitic limestone	180	
Light-gray limestone, with much chert	80	
Light-gray limestone, crinoid remains	44	
Light-gray cherty limestone	71	
Light-brown cherty limestone	23	
Light-grayish crinoidal limestone	18	
Gray shaly limestone	30	
Light grayish-brown massive limestone, Kinderhook	62	
Brown, sandy limestone, Chemung	27	
Black limy shale	173	
Light brownish-gray limestone	78	

ST. FRANCIS MOUNTAINS DISTRICT.

The St. Francis Mountains district includes the southeastern of the State, with the exception of the swampy region. Portio the following counties are within its borders: Jefferson, Washing St. Francois, Ste. Genevieve, Iron, Reynolds, Madison, Perry, Girardeau, Bollinger, Wayne, and Carter. The catchment are most of the flowing wells in this district is in the St. Francis M tains. Flowing wells are located at or near the following plac Soto, Jefferson County; Bismarck, St. Francois County; Pilot and Ironton, Iron County; Fredericktown, Madison County; hontas, Cape Girardeau County, and Grandin, Carter County.

CAPE GIRARDEAU COUNTY.

BURFORDVILLE.

In Burfordville, Cape Girardeau County, in sec. 32, T. 31, is a well owned by J. H. Estes and drilled by Henry Bresuke following log was received from Messrs. M. L. Fuller and S. San

Log of Estes well, Burfordville, Cape Girardeau County.

Soil	
Sand rock	
Limestone, water comes in at top	

POCAHONTAS.

In Pocahontas, near the center of sec. 31, T. 33, R. 13, is a well owned by Thomas D. Hope. Depth, 62 feet; casing, 6-inch; flow, weak; date of completion, May, 1903; drillers, Steimel & Reid, Jackson; cost of well, $100; surface formation, Hudson group. The water flowed from a clay opening immediately under 50 feet of solid limestone. No variation in pressure has been noted, and pumping merely stops the surface flow. The water is hard, cool, agreeable to the taste, and is used for all purposes.

CARTER COUNTY.

GRANDIN.

Four wells were drilled in Grandin on the land of the Missouri Lumber and Mining Company, in sec. 11, T. 25, R. 2 E, on low ground and near a stream. Through the courtesy of Mr. C. C. Sheppard, superintendent of the company, the writer received a set of drill samples and data from well No. 3 of this group, from which the accompanying log was obtained. One of the wells flows, and the other three stand full. Well No. 3 is 206 feet deep; altitude above tide, about 580 feet; casing, 8-inch, 18 feet to rock; date of completion, 1900; cost of well, about $400; surface formation, probably Bonneterre limestone. The principal source of water was reached between 140 and 160 feet, in a limestone rock that was much seamed and fissured. This and the other wells of the group were drilled to supply good water for boiler purposes. Each well will furnish about 50,000 gallons when pumped for twenty-four hours, and the supply is not diminished. The water is hard, pure, and cold. One of the wells was sunk to a depth of 320 feet, but the record was not preserved.

Log of well No. 3, Grandin, Carter County.

	Thickness.	Depth.
	Feet.	*Feet.*
Pink siliceous limestone (dolomite), with mamillary quartz cavities and some siliceous particles	64	64
Light pinkish-gray siliceous dolomite, increase in silica	17	81
Same, with some chert; more siliceous	20	101
Similar, but finer grained, more angular particles, with increase of white chert and silica	30	131
Similar, highly siliceous, with some white chert	10	141
Similar, some white chert, small cavities in particles	10	151
Decided change; large angular fragments of light-gray, highly siliceous dolomite; no chert	10	161
Gray, coarse siliceous dolomite, with irregular cavities that are slightly iron stained	10	171
Finer grains of highly siliceous pink dolomite merging into pink quartzite	20	191
Limpid, milky-white to pink quartzite and highly siliceous dolomite	15	206

This well is all in one formation, and probably near the base of the Bonneterre limestone or Fourth Magnesian limestone of Swallow.

IRON COUNTY.

IRONTON.

The records of two nonflowing wells at Ironton, Iron County, are as follows:

The Ironton Manufacturing Company well was drilled by T. J. Lemaster, of De Soto, in 1902, to a depth of 300 feet, with a 6-inch bore. The main source of water was found at 100 feet, but other water-bearing beds were found at 15, 75, 150, and 200 feet. The water, which contains iron and sulphur, rises within 5 feet of the surface, whence it is pumped to a feed boiler. The well cost $350.

The Clark Manufacturing Company has a well, drilled in 1900, which is situated in a valley. It has a 6-inch bore and is 305 feet deep. The main source of the water was found in the rock at 301 feet. Water rises to the surface, but does not flow. It is hard, contains a little sulphur and iron, and is used for boiler purposes. It is lowered 20 feet by pumping.

PILOT KNOB.

Several prospect holes sunk by the Iron Mountain Company near Pilot Knob with a 1¼-inch diamond drill, about 1890, have resulted in flowing wells. The first one of these is located half a mile north of Ironton, close to the west side of the St. Louis, Iron Mountain and Southern Railway. It has a feeble flow of slightly chalybeate water, with a temperature of 56° F. when the air temperature is 78° F. Another well about 1,000 feet north of this one raises the water about 2 feet above the surface, whence it is conveyed to a public watering trough. About 1,000 feet still farther north is another well that raises the water about 4 feet above the ground and also supplies a watering trough. The temperature of this water is 59° F. when the air temperature is 78° F. One-half mile west of the last-named well, and just west of the Old Fort, is another feebly flowing well of chalybeate water. A quarter of a mile northeast of this is the last well of the group. All records of depth have been lost. The rocks dip to the west from Pilot Knob.

JEFFERSON COUNTY.

DE SOTO.

The town of De Soto is situated in a valley near the head of Joachim Creek, at an altitude of 498 feet. Its main street runs parallel with the St. Louis, Iron Mountain and Southern Railway, and a number of deep wells are sunk along both sides of this street. The owners, location, and depths are as follows:

1, James Hopson, No. 1, Pratt and Second streets, 265 feet; 2, Electric Light Company, Main street, about 200 feet; 3, Sherlock's mill, East Second and Clement streets.

about 200 feet; 4, Crawford lumber yard, East Clement and East Third streets, 235 feet; 5, Hammel Lumber Company, Boyd and Second streets, 310 feet; 6, John Hopson, Main and Plattin streets, 185 feet; 7, James Hopson, No. 2, Main and Miller streets, 225 feet; 8, Packing house, East Third and Miller streets, 190 feet; 9, R. M. Booth, East Main and Pratt streets, 200 feet; 10, S. W. Crawford, Main and Easton streets, 200 feet; 11, G. Hammel, Main and Williams streets, 300 feet; 12, John L. Rouggly, Main and Stone streets, 300 feet; 13, 14, City Water Company, pump house, 300 feet; 15, W. J. Manthes, 265 feet; 16, Commercial Hotel, Main street, about 200 feet; 17, Herman Hammel, Main street between Clement and Mineral streets, about 200 feet; 18, Dr. H. E. Zorn, Main and Mineral streets, 200 feet; 19, George Mann laundry, Main and Stewart streets, 200 feet; 20, Herman brickyard, three-fourths mile north of city, about 200 feet; 21, Electric-light plant, 185 feet.

These wells are nearly all 6-inch drill wells, generally cased with 4-inch casing to a depth of about 150 feet. No. 3 has ceased to flow, the water probably wasting, as the casing is only 80 feet deep. No. 10, the Crawford well, and No. 11, the Gus Hammel well, have both ceased to flow, owing to the fact that other wells seem to have tapped their source. No. 12, the Rouggly well, supplied the drinking water for the Louisiana Purchase Exposition. Nos. 13 and 14, the City Water Company wells, flow about 70,000 gallons in twenty-four hours, and these, when pumped, cause a number of other wells in the neighborhood to stop flowing. Nos. 16, 17, 18, and 19 have all ceased to flow.

James Hopson sunk his first well in 1886, on the corner of Pratt and Second streets, in the endeavor to find soft water for the boiler at his mill. The first flow was obtained at a depth of 100 feet; the second, which raised the water 17 feet above the surface, was reached at a depth of 225 feet. The temperature was 58° F. when the air temperature was 83° F. This well and mill are now owned by Henry Lupp.

One well was sunk on a hill 97 feet above Main street to a depth of 328 feet. Water rose within about 80 feet of the surface, a level corresponding to that of the flowing wells which are situated at a lower point. The third well sunk in the city was the packing-house well. The surface at this point is about 10 feet below the general level of the town. A strong flow was struck at 115 feet, with a second flow at 190 feet. These two flows are separated by two pipes. The first comes from a sandstone, probably the Roubidoux, and the second from the Gasconade limestone. The surface formation is the Jefferson City limestone.

The flow of all the wells in this vicinity, included in a valley about a mile long and half a mile wide, is affected, in one way or another, by various causes. For example, the John Hopson well, No. 6, situated about 1,200 feet northwest of the waterworks wells, stops flowing when the latter are being pumped. As soon as the pumping is discontinued the Hopson well flows again at an abnormally rapid rate. When the Crawford well, No. 10, was sunk, it had a good flow, but

when the Gus Hammel well, No. 11, was put down, the Crawford well stopped flowing until the Hammel well was shut off, the latter being 12 feet higher than its neighbor. The wells in the southern part of the town have the strongest flow, and since so many have been sunk in this vicinity most of those to the north have ceased flowing.

The regional dip of the rocks in this district, from Bismarck to De Soto, is from the St. Francis Mountains to the northeast. This fact, together with the peculiar phenomena connected with the flowing of the wells, seems to indicate that the catchment basin for this De Soto group is in the St. Francis Mountains.

One mile up Joachim Creek from De Soto is a large spring which comes to the surface with a strong flow, bringing with it fine white sand, and it is probable that this spring is one of the natural outlets of the artesian pressure from the Roubidoux sandstone.

All the wells in the De Soto basin show signs of decreasing pressure. This is undoubtedly because of the escape of waters through crevices in the rocks, due to bad casing, and because so many wells have been sunk within the limits of so small an area. The expense of drilling in this region varies from $1.50 to $2 per foot; generally about $1 for the first 100 feet, $1.50 for the next 100, and $2 for the third 100 feet. The water is clear, cool, and pure, containing a little iron. The temperature varies from 56° to 57° F. That of the waterworks well is 56° F. when the air temperature is 80° F. The city is replacing the old waterworks plant with one more modern, to supply which two wells a few feet apart, both with a 10-inch bore, have been sunk. A pump house has been erected and a pump is being placed for the purpose of raising the water to a reservoir that is being built on a hill 220 feet above the city. This will provide De Soto with one of the best and purest water supplies in the State. No analysis of these waters has ever been made.

It is stated that at Hematite, 8 miles north of De Soto, a prospect hole drilled to a depth of 300 feet struck flowing water.

MADISON COUNTY.

FREDERICKTOWN.

On the farm of Mrs. Emma Copeland, in the NW. ¼ sec. 2, T. 33, R. 7, near Mine La Motte, is a diamond-drill well sunk about 1900 to a depth of 300 feet. The water flows feebly about 3 feet above the surface. It is clear and cold, and is used for stock purposes.

Four wells were bored on the Sheldon estate, in sec. 25, T. 34, R. 7, to a depth of about 300 feet each, by Mr. H. R. Amling, of Fredericktown. They all had a strong flow, but when the casing was pulled out they filled up and stopped flowing.

On the farm of F. M. Griffin, in the NW. ¼ sec. 14, T. 33, R. 7, a well was bored in March, 1905, to a depth of 304 feet. Water rises 5 feet above the surface. It is clear and cold, and is used for stock purposes.

In the NW. ¼ of sec. 16, T. 33, R. 7, a well was sunk by the North American Mining Company to a depth of 300 feet. It has a feeble flow.

All the wells at Fredericktown are situated on the west side of a dividing ridge of the St. Francis Mountains, and the rocks dip to the southwest.

PERRY COUNTY.

PERRYVILLE.

The Perryville Ice Company completed a well to a depth of 386 feet, with a 6-inch bore, cased to the bottom. This is located a quarter of a mile east of Perryville. Water was obtained in an opening at a depth of 60 feet, probably an underground stream. Pumping does not change the level. The water is soft, and is used for boiler purposes and in making ice. Rock was struck at a depth of 14 feet, and with the exception of the crevice opening at 60 feet, solid limestone continued to a depth of 300 feet.

ST. FRANCOIS COUNTY.

BISMARCK.

Bismarck is situated in a basin with outcroppings of porphyry on the west, south, and east. Several flowing wells are located in or near the town. The catchment basin for the group is in the porphyry hills to the west and south.

One of the Tullock wells is situated in sec. 16, T. 35, R. 4. It is 313 feet deep and flows about 3 gallons per minute. It was drilled by Ben Hoskins, of Central, in 1901, and is 120 feet below the railway station at Bismarck, according to the barometer. The water is clear, fairly soft, and has a temperature of 56° F., the air temperature being 75° F. This is a diamond-drill well, with a 1¼-inch bore, and was drilled by the Iron Mountain Company. It goes 20 feet into granite. Mr. Tullock's second well was sunk in 1891, by the same company, in sec. 17, T. 35, R. 4, to a depth of 240 feet. It is 15 feet higher than the first well, according to the barometer. The casing was drawn out of this well, and the water wastes away at the surface. The rocks in both cases dip to the west, away from the porphyry hills. Neither the logs nor the analyses of these wells have been preserved. They probably obtain water from the Bonneterre limestone.

The Stephen Fine well is situated 1½ miles west and a little north of Bismarck in a little valley close to a small branch, about 115 feet

below the town by barometric measurement. It is about 180 feet deep, and has the strongest flow of any in the group, raising the water about 12 feet above the surface. The water is clear, pure, and cold, having a temperature of 56° F., when the air temperature is 80° F. This well, like the two preceding, probably obtains water from the Bonneterre limestone. The rocks dip to the west. About 150 feet distant from this well is another which flows feebly in wet weather.

The John Neujus wells are situated in the NE. ¼ lot 2, sec. 5, T. 35, R. 4. They were drilled in 1894 and 1901 with a 1¼-inch diamond drill. Barometrically, they are at the same altitude as the town of Bismarck. They are about 250 feet deep, cased a few feet to rock, and have a feeble flow reaching only about 4 feet above the surface. The water commenced to flow at a depth of 90 feet. It is clear, pure, soft, and cold, with a temperature of 57° F., the air temperature being 80° F. The wells are sunk within a few feet of each other in a little swamp. Mr. Neujus stated that there are thirteen small springs within a radius of 13 feet of the wells. He has built a fish pond which is fed by these springs. Several other drill holes were sunk in the immediate vicinity, at a surface altitude of 6 to 8 feet higher than the wells just described. In them water stands but a few inches from the surface. The Neujus wells are all probably in the Elvins formation, and the rocks dip to the north.

A diamond-drill well, with a 1¼-inch bore, was sunk to a depth of 300 feet on the farm of William Gruner, one-eighth of a mile south of the Neujus wells. It flows only a part of the time, and then but feebly.

It is stated that two prospect holes sunk on Flat River, near Central, flowed for a time.

SOUTHEASTERN SWAMP DISTRICT.

GENERAL ARTESIAN CONDITIONS.

The most interesting artesian district in the State, that of the southeastern lowlands, includes but a portion of the true swamp district, which extends into the adjoining States of Illinois, Kentucky, Tennessee, Mississippi, and Arkansas. This Missouri portion embraces the following counties: Scott, Mississippi, New Madrid, Stoddard, Butler, Dunklin, and Pemiscot.

The only flowing wells in the embayment region in Missouri are those at Morehouse, New Madrid County, and Campbell, Dunklin County, on the north and east sides of the embayment.

Attention has been briefly called to the fact that the Missouri lowlands occupy the northwest corner of the great Mississippi embayment. Into this cone-shaped trough empties the drainage of the southeastern flanks of the Ozarks from Missouri, bringing a vas

quantity of water, not only over the surface by means of the rivers and smaller streams, but also through those porous aquifers, the Cambro-Ordovician sandstones, cherts, and porous limestones, which have a strong southeasterly dip into this basin. That these rocks are loaded with water is shown by the immense springs and underground streams that everywhere abound in this region. In fact, some of the largest springs in the world are found in close proximity to this district. From the north comes the drainage from the southern flanks of the St. Francis Mountains and southern Illinois, the volume of which is indicated by the interesting phenomena discussed in the consideration of the well at Benton, Scott County (p. 179). From the east is received the drainage from the plateau of western Kentucky and Tennessee, the rocks all dipping strongly westward from the central catchment basin of these two States.

This embayment region, which was largely eroded during later geologic time, has been gradually filled from the south by Cretaceous, Tertiary, and Quaternary deposits consisting, as is shown by the well records of this district, of alternating layers of incoherent sands and thick, tenacious clays, forming perfect water bearers separated by impervious beds. These well records and cross sections also show that the beds not only dip strongly toward the center of this basin from each side, but that they thicken and dip strongly to the south. Into these great deposits of sand a vast volume of water pours from the west, north. and east, causing an immense artesian pressure; and when it is remembered that the alternating impervious layers are not solid rock, but thick beds of flexible, tenacious clay, underlain by water-logged, incoherent sands, it is not difficult to understand why this is a district of unstable equilibrium, subject to the disturbances manifested in the frequent slight earthquake shocks which have produced numerous fissures and fault scarps throughout the entire region.

Flowing wells are confined entirely to the outer margin of the embayment, as at Cairo and Mound City, Ill.; Hickman, Ky.; Dyersburg and Memphis, Tenn.; and Campbell, Morehouse, and Grandin, Mo. Numerous deep wells near the center of the embayment do not flow. This interior region of nonflowing wells is saturated with water which is constantly coming to the surface in lakes, swamps, and streams, and which is continually renewed from a deep-seated source—a living supply, supporting the finest game fish. The escape of this volume of water through fault cracks and fissures relieves the pressure below, and thus tends to preserve an equilibrium and at the same time creates conditions unfavorable to the existence of flowing wells.

The logs given on pages 175 and 177 indicate the frequent occurrence of iron, iron pyrites, and lignite, which in decomposing produce in the water such impurities as iron, sulphur, and small amounts of gas. Chemical analyses show that water taken from wells near the edge of

the basin is, as a rule, purer than that from those farther in, for the reason that the water in the outer wells, being nearer its source, has been in contact with these substances for a shorter time, and consequently is less impregnated with impurities than the waters that are obtained farther from the catchment area.

BUTLER COUNTY.

POPLAR BLUFF.

At Poplar Bluff, Butler County, W. F. Alfrey sunk a well to a depth of 517 feet. He states that the water rose within 15 feet of the surface, and that a 12-horsepower pump could not lower it an inch. He further gives the interesting fact that in 1892, after an earthquake shock, the well was nearly ruined, there being at times hardly enough water to run the factory. It is to be regretted that no log has been preserved, either of this or of other wells at Poplar Bluff.

The ice factory has a well about 400 feet deep, the Oil Well Supply Company one about 200 feet, the Missouri Pacific Railway one about 200 feet, and the Palmer Company one about 250 feet deep.

Mr. W. S. Randall, postmaster at Poplar Bluff, who furnished the above data, also stated that in the bottoms, at a depth of less than 30 feet, the water is hard, impregnated with iron, and comes from a black to reddish quicksand. Below 30 feet good water is obtained from a white quartz sand. Most of the sand in the vicinity has well-rounded globular grains. In this surface stratum of iron-bearing sand are mounds of sand about 3 feet high and from 10 to 20 feet in diameter, which are termed "sand blows." It is claimed that pipes put down in these sand blows give a better quality of water—a significant fact. This condition is very general through the Missouri portion of the embayment district, the best water being obtained in the white sand beneath the reddish surface sand. It is the custom in this region to drive a galvanized-iron pipe with a conical strainer at the end down into this white sand, from which a good water supply may be pumped.

DUNKLIN COUNTY.

CAMPBELL.

At Campbell, Dunklin County, a well is located on the land of the Campbell Lumber Company. Depth, 960 feet; elevation above tide, about 310 feet; casing, 4-inch, to 910 feet; temperature of water, 72° F.; flow, 16 gallons per minute; date of completion, September, 1902; drillers, Johnson & Fleming, Memphis, Tenn.; cost, $3,000. The principal source of water was found at 940 feet in sand, and another water-bearing horizon was found at 145 feet. The water is somewhat soft, though rather saline, and contains sulphureted hydro-

gen. The following log of this well was furnished by Mr. Wm. B. Johnson,[a] of Memphis, Tenn.:

Log of well of Campbell Lumber Company, Campbell, Dunklin County.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess? (112 feet):		
Yellow clay, a little darker than that on Crowleys Ridge	112	112
Lafayette (43 feet):		
Orange sand and gravel; the sand has many white, loamy clay nodules mixed in it	43	155
Lagrange formation (785 feet):		
Very hard black and brown clay or marl, with numerous very hard strata from 1 to 23 inches thick, composed largely of iron pyrites. At some point between 700 and 750 feet a bed of logs 10 or 12 feet thick was penetrated. This clay differed from any other bed struck in the bottoms in containing no sand strata, and not even a trace of the "gray sand" found in other wells was noted	785	940
Ripley sands (20 feet):		
Very fine black sand, with a large percentage of mica in small grains. Water headed about 7 feet above surface and flowed 16 gallons per minute had brackish taste	20	960

The water from this well is used for boiler and drinking purposes. It is probable that the bottom of the well is not far from bed rock.

NEW MADRID COUNTY.

MOREHOUSE.

In Morehouse, New Madrid County, in sec. 31, T. 26, R. 13, is a well owned by the Himmelberger-Harrison Lumber Company. Depth, 780 feet; altitude above tide, about 330 feet; casing, 10-inch pipe at top, 6⅝-inch casing at bottom; flow, 200 gallons per minute; date of completion, summer of 1902. This well was drilled through the estuary deposits to solid limestone. The pressure raises the water 18 feet above the surface, and no variation has ever been noted. Though the water is somewhat saline, it is used for drinking. The accompanying log and some samples of drillings for study were furnished by Mr. John H. Himmelberger:

Log of well at Morehouse, New Madrid County.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess (30 feet):		
Clay	30	30
Lagrange (218 feet):		
Coarse sand	110	140
Gravel	10	150
Gumbo, or brown clay	40	190
Brown quicksand	40	230
Gumbo	10	240
Cemented gravel	8	248
Porters Creek (Eocene) (218 feet):		
Gumbo	197	445
Rock	1	446
Gumbo	20	466
Ripley sands (Cretaceous) (224 feet):		
Fine white sand	224	690
Cambrian (probably Gasconade limestone) (90 feet):		
Limestone	40	730
Sandstone	15	745
Limestone, full of crevices and badly broken	35	780

[a] The writer is indebted to Mr. Johnson for many favors and much valuable information in regard to the wells of this district. The work of the geologist would be greatly facilitated if other drillers would take as much interest in preserving data as has been shown by Mr. Johnson.

The 30 feet designated as probably loess and the 110 feet of coarse sand included in the Lagrange formation are doubtfully so placed. The 90 feet of limestone and sandstone penetrated at the bottom is a light-gray, highly siliceous, shaly rock, probably the Gasconade limestone. This well record is a particularly valuable one, as it gives the thickness of the estuary deposits at this point.

Morehouse is situated in what was probably one of the early channels of Mississippi River, and the 140 feet of sand and clay at the surface may have had its origin as a river deposit. Mr. Himmelberger, in a personal letter, states that in going through the white sand above the limestone, fragments of charred and decayed wood were brought to the surface. He furnishes an analysis of the water of this well, made at the Missouri State University.

Analysis of water from well at Morehouse, New Madrid County.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	12	Sulphate radicle (SO_4)	123
Calcium (Ca)	208	Chlorine (Cl)	1,437
Magnesium (Mg)	55		
Sodium (Na)	649		2,484

The following log of this well, furnished by Mr. Otto Kochtitzky, of Cape Girardeau, varies slightly from that given by Mr. Himmelberger:

Log of well at Morehouse, New Madrid County.

	Thickness.	Depth.
	Feet.	*Feet.*
Sand and fine gravel	66	66
Coarse sand	40	106
Sand	35	141
Black soapy clay	9	150
Dark-blue clay	22	172
Blue clay and sand	65	237
Sand and clay	20	257
Sand and blue clay	22	279
Blue clay, except 1 foot of shale	148	427
Sand, except about 2 feet of gravel on limestone bed	269	696
Limestone	90	786

NEW MADRID.

A well was sunk at New Madrid by the Mississippi River Commission in 1881. About 20 borings were made in the vicinity, two of which extended to a depth of over 200 feet, but none of them resulted in flowing wells. Mr. Henry Moss, who was a member of the Commission, stated that a great many wells were sunk all along the river from Listers Island, 20 miles north of New Madrid, to Fort Pillow,

[a] Expressed in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at the United States Geological Survey.

near Osceola, 90 miles south of New Madrid. Most of these were about 200 feet deep, and none of them less than 125 feet. Whenever these drill holes penetrated through the clay layer into the deep sand, water and sand would shoot up to a height of 30 or 40 feet in the pipe, the sand clogging the pipe in the bottom. The following is the log of well No. 9,[a] at New Madrid, which was begun about 12 feet above high-water mark:

Log of well near New Madrid, New Madrid County.

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium and possibly some Lafayette (64.3 feet):		
Sand, gray above and light brown and more clayey below	4	4
Clay, blue above and sandy below	31.6	35.6
Sand, dark gray, containing particles of lignite and layers of blue clay	9.4	45
Gravel, with some sand and lumps of lignite and decayed wood	19.3	64.3
Lagrange (149.7 feet):		
Clay, blue, containing wood showing fiber	5	69.3
Sand and gravel	17.3	86.6
Sand, thin layers of clay, interstratified with some gravel	24.3	110.9
Clay	20.3	131
Sand, yellowish and reddish, interstratified with thin layers of yellowish and grayish pebbly clays	40.2	171.2
Clay, brown	10.8	182
Sand, gray	17.6	199.6
Clay, gray, with thin layers of fragments of lignite	1.4	201
Sand, gray, with few thin layers of gray clay	13	214

Another well sunk to a depth of 207 feet had a similar section. A strong body of water was found in the lowest gravel, below 192 feet.

PEMISCOT COUNTY.

CARUTHERSVILLE.

The city waterworks well at Caruthersville, Pemiscot County, is located in sec. 13, T. 18, R. 12; depth, 428 feet; altitude above tide, 280 feet; casing, 5-inch to bottom; temperature of water, 60° F.; date of completion, March, 1903; drillers, Johnson & Fleming, Memphis, Tenn.; cost, with pumping machinery, $2,500. Water was struck at 25 feet, but the principal supply was found at 268 feet, from which the water rose within 10 feet of the surface. It is pumped into a standpipe 100 feet high by two Gardner pumps and distributed by 4½ miles of 4, 6, and 8 inch mains. The pressure is 75 pounds, which may be increased to 120 pounds for fire purposes. A daily consumption of 500,000 gallons does not affect the supply. The water contains a large amount of iron and is objectionable to some on account of the yellow precipitate. The mouth of the well is 25 feet above Mississippi River, just north of the city, and the water level is influenced by the rise and fall of the river, although it is normally higher than the river level.

[a] Miss. River Comm. Rept. of Progress, 1881, p. 180.

Two analyses of the water from this well have been made. The one here given was furnished by Doctor Byers, mayor of the city, who has also supplied other valuable data in regard to this region:

Sanitary analysis of Caruthersville city water.

[Analyst, Dr. R. B. H. Gradwohl, St. Louis.]

	Parts per million.		Parts per million.
Nitrogen as free ammonia	0.06	Oxygen consumed	2.5
Nitrogen as albuminoid ammonia	.082	Chlorine	6
Nitrogen as nitrites	0	Alkalinity	100
Nitrogen as nitrates	.22	Total solids	120

The test for iron shows but a trace—about 3 parts per million. This represents a fairly good drinking water.

The amount of iron given in this analysis is manifestly incorrect. The water probably stood for some time, which allowed the iron to precipitate. Doctor Byers states that another analysis, now lost, gave over 34 parts of iron per million.

A well at the oil mill in Caruthersville, 385 feet deep, furnishes water that is apparently of the same character as that from the preceding well and is used for steam purposes.

The ice-factory well was first sunk to the depth of 715 feet. The casing was afterwards pulled up and a strainer put on at 416 feet, much better water being obtained. The log of the well given below is furnished by Mr. W. B. Johnson, who states that the formations in all the Caruthersville wells are uniform:

Log of ice-factory well, Caruthersville, Pemiscot County.

	Thickness.	Depth.
	Feet.	*Feet.*
Black sandy loam, shading to sand	19	19
Sand and gravel, practically same as river sand (gravel mostly large)	154	173
Very hard blue clay	32	205
Very soft blue clay, mixed with sand	175	380
Gray sand, mixed with lignite	335	715

Mr. Johnson states that drilling was stopped in this gray sand at 715 feet, and that as no change was found the pipe was pulled back and the strainer put on at 416 feet. The well yields 400 gallons per minute by pumping.

RIPLEY COUNTY.

NAYLOR.

A deep well is reported near Naylor, Ripley County, in sec. 33, T. 22, R. 4 E., on the property of the Doniphan Lumber Company. This was sunk to a depth of 990 feet. The log was not preserved. An abundance of water was found all the way down, and all efforts to case it off proved futile. The well was drilled for gas. When it was abandoned the water stood at the surface.

SCOTT COUNTY.

BENTON.

In the northeast corner of the public square in Benton, in sec. 13, T. 28, R. 13 E., is a well owned by the county. Depth, 1,500 feet; altitude above tide, 470 feet; casing, 6-inch, to 160 feet; temperature of water, 60° F.; of air, 80° F.; date of completion, December, 1904; driller, Charles S. Wise, St. Louis; cost, with pumping machinery, $10,000. This well was put down by the county court in order to provide water for the court-house and jail. Benton is situated more than 100 feet above the level of the swamp country—an isolated elevation that was formerly joined to Crowleys Ridge. The principal supply of water was found between 1,200 and 1,500 feet. One of the very interesting peculiarities of this well is the fact that though drilling was very hard between the limits just mentioned, not more than a quart of the cuttings could be secured. The water supply seems to come from crevices in the rock, and the last cuttings obtained were from a depth of 1,440 feet, though the well is 1,500 feet deep. Evidently a very large body of water flowing through these crevices carried off the drillings. This strong flow is from the north toward the artesian basin, as is shown by the dip of the rocks in the surrounding region—a significant fact, that is again referred to on page 173. Other water-bearing beds were found at depths of 150, 180, 480, and 600 feet. The water stands in the well at about 120 feet from the surface, and a 4-inch pump, worked continuously for three days, did not affect the level.

The writer is indebted to Mr. Albert De Reign, water commissioner of Scott County, for a carefully kept record of this well, for samples of drillings, and for much information resulting from his close observation of artesian conditions in this locality. With reference to the height of the water in this well, he states that the tubing, with a rubber packer, was first inserted at 600 feet. It was then raised and a test made at every joint, i. e., every 20 feet, resulting in no perceptible difference in the height of the water. Then 1,460 feet of 2-inch tubing was inserted in the same way. At this depth the packer was sprung and all water from above satisfactorily cut off. After about thirty minutes a test was made with a plumb line and the height of the water carefully measured, both in the interior of the 2-inch tubing and on the outside. This test showed that the water had risen 10 feet. Similar tests were then made as the tubing was raised at intervals of 20 feet. At no joint, however, did the water rise higher than at the 1,460-foot level. The present depth of water from the surface is the same as when the first test was made, viz, 120 feet. It was very difficult to control the water above 1,460 feet, from the fact that there were several perpendicular and diagonal crevices, as well as

cavities, leaving no smooth wall against which the packer at the end of the tube could find lodgment to completely shut off other water.

From samples of drillings that were carefully preserved by Mr. De Reign and sent to the writer, the following log of the well is given. It is noticeable that no sandstone occurs below 475 feet, which makes it very difficult to correlate the section. It is very probable, however, that sandstone beds may have occurred, the drillings from which were washed away in the last 300 feet, as already suggested.

Log of well at Benton, Scott County.

	Thickness.	Depth.
	Feet.	*Feet.*
Tertiary (158 feet):		
Clay, yellow		55
Gravel, hard	10	65
Iron ore, yellow bowlders, soft	30	95
Quicksand	36	131
Lithographic stone, brown, medium	9	140
Quicksand and metamorphic sandstone	18	158
"Richmond" and Kimmswick ? (272 feet):		
Limestone, gray, medium	22	180
Limestone, brown, medium; strong odors of gas	50	230
Limestone, brown-buff, medium, with sand	200	430
St. Peter sandstone (45 feet):		
Sandstone, yellow, medium	8	438
Sandstone, gray, medium	9	447
Sandstone, yellow, medium coarse	28	475
Jefferson City limestone (225 feet):		
Limestone, blue, medium	95	570
Trenton limestone, brown, medium; gas odor	30	600
Limestone, blue, medium	30	630
"Gypsum" (calcite?), white, soft; here 200 gallons of water per minute rose within 100 feet of top	20	650
Limestone, gray, hard	5	655
Shale, black, medium	45	700
Roubidoux and Gasconade (540 feet):		
Limestone, blue, gray, medium	135	835
Limestone, gray, hard	195	1,030
Limestone, blue, gray, hard	60	1,090
Limestone, gray, hard	82	1,172
Limestone, blue, gray, hard	8	1,180
Limestone, blue, hard	20	1,200
Limestone, buff, gray, hard	40	1,240
Upper Elvins or lower Gasconade (200 feet):		
Dolomite, brown, hard	80	1,320
Dolomite, gray, hard	30	1,350
Dolomite, buff, hard	15	1,365
Dolomite, brown, hard	5	1,370
Dolomite, gray, hard	50	1,420
Dolomite, brown, gray, hard	20	1,440
Elvins (60 feet):		
Dolomite, black, hard	60	1,500

The last record was taken at about 1,440 feet, no drill cuttings being obtainable during the remaining 60 feet, although the drilling was hard.

A sample of the water from the Benton well was sent to Prof. Harrison Hale, of Drury College, who made a partial analysis, which is given below. The water was taken from the well after continuous pumping for three weeks.

Partial analysis of water from well at Benton, Scott County. [a]

	Parts per million.		Parts per million.
Calcium (Ca) [b]	77	Sulphate radicle (SO_4)	0
Sodium (Na)	22		
Carbonate radicle (CO_3)	144		274
Chlorine (Cl)	31	Temporary hardness	260
Iron (Fe)	0	Permanent hardness	0

WELLS OUTSIDE OF MISSOURI.

CAIRO, ILL.

Several flowing wells have been sunk in the city of Cairo and immediate vicinity. The writer is indebted to Mr. Otto Kochtitzky for the following record of the well at the Halliday Hotel:

Log of flowing well at Halliday Hotel, Cairo, Ill.

	Thickness.	Depth.
Alluvium (109 feet):	*Feet.*	*Feet.*
Sand and clay	50	50
River sand	59	109
Lagrange (237 feet):		
Sand and gravel	10	119
White sand	176	295
Kaolin; first artesian water at 698 feet	6	301
Gravel and sand, mixed with iron	45	346
Porters Creek (187 feet):		
Yellow clay	5	351
Kaolin	27	378
Shale	155	533
Ripley sands (45 feet):		
Sand and cement gravel	45	578
Mississippian (276 feet):		
Flint rock	19	597
Sand and cement gravel	13	610
Flint rock	50	660
Sand and gravel	20	680
Gray lime rock; second artesian water at 792 feet	174	854

HICKMAN, KY.

At Hickman, Ky., is a well 917 feet deep, owned by H. A. Tyler. It is 130 feet above the railroad and 133 feet above the high-water mark on the Mississippi River gage. The following record was furnished and the correlations made by Prof. L. C. Glenn, of Nashville, Tenn.:

Log of Tyler well, Hickman, Ky.

	Thickness.	Depth.
Loess (80 feet):	*Feet.*	*Feet.*
Yellow clay	80	80
Lafayette (10 feet):		
Soft sand	10	90
Lagrange (627 feet):		
Soft blue clay	460	550
Very fine sand	6	556
Tough blue clay	144	700
Sand	17	717

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

[b] CO_2 given equals 192, calculated as all $CaCO_3$.

The section of a near-by hole, which is 850 feet deep, shows that the lowest sands mentioned in the above log extend to a depth of at least 830 feet.

DYERSBURG, TENN.

Messrs. Johnson & Fleming report the following section at Dyersburg, Tenn.:

Log of well at Dyersburg, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Lafayette (90 feet):		
Conglomerate, mostly wash from the hillside	42	42
Sand and gravel	48	90
Lagrange (538 feet):		
Very hard blue and brown clay	430	520
White clay, very sticky and hard to penetrate	80	600
Coarse white sand, considerably lighter in color than the Memphis sand, but similar to that in having small particles of lignite in it	28	628+

The elevation of the well mouth is 1 foot above high water in Mississippi River, 1897. The water rose to a height of 12 feet above the surface and flowed 102 gallons per minute at the surface. It was analyzed by Dr. Felix Paquin, city chemist, Memphis, and pronounced very good and practically the same as the Memphis water, though to the writer it seemed to contain more iron.

JONESBORO, ARK.

Deep wells have been reported at Jonesboro, Ark., where it is said that rock was struck at a depth of 1,200 feet, which gives the depth of the embayment deposit. It is unfortunate that the logs were not preserved.

MARKED TREE, ARK.

At Marked Tree, Ark., is a well owned by the Chicago Mill and Lumber Company, of Blytheville, Ark. The following record is furnished by Mr. W. B. Johnson:

Log of well at Marked Tree, Ark.

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium and Lafayette (?) (220 feet):		
"Buckshot," shading to sand	27	27
Orange sand and gravel	193	220
Lagrange formation (clay, 146 feet):		
Soft white clay	12	232
Very hard blue clay	63	295
Soft, sandy blue clay with thin streaks of sand	71	366
Lagrange formation (sand, 32 feet):		
Gray sand, same as at Memphis	32+	398+

This is one of three wells made by Mr. Johnson at this point, all of which had similar logs. When the gray sand was struck, water rose within 3 feet of the surface. Three gallons per minute were pumped on a test, this being the full capacity of the pump. The water has been analyzed as follows, and reported excellent, with about the same amount of iron as the Memphis water.

Analysis of water from well at Marked Tree, Ark.[a]

[Analyst, Felix Paquin.]

	Parts per million.		Parts per million.
Silica (SiO_2)	2.4	Sulphate radicle (SO_4)	4.7
Calcium (Ca)	9.4	Chlorine (Cl)	5.3
Magnesium (Mg)	.89		
Sodium (Na)	3.5		39.19
Carbonate radicle (CO_3)	13		

MEMPHIS, TENN.

At Memphis, Tenn., there are 141 artesian wells, most of them flowing, mainly connected with the city waterworks system, which is one of the best in the country. The following condensed information and log, as well as samples of drillings, were furnished by Messrs. Lanhan and Davis, engineers at the waterworks. Both the engineers state that in these wells there is a continuous flow of fine sand, brought to the surface by artesian pressure, from depths ranging from 450 to 600 feet. A brass strainer, with openings one one hundred and fiftieth of an inch in width, is placed in the bottom of each well, and these are so rapidly worn by the sand that they have to be replaced in from three to five years, and every precaution has to be taken to keep this sand from the valves and piston rods of the pumps. These wells are tapped at depths varying from 40 to 60 feet and the water conveyed by brick tunnels to a central reservoir at the pumping station. It is necessary occasionally to clean the sand out of these tunnels. Recently one was found nearly filled with it. A variation of 12 feet in the level of the water in the wells has been noted between the wet and the dry seasons. The temperature of the water varies from 60° to 62° F.

The section given below is the log of the deep well on Quinby street, near Robinson, in which the water rises within 14 feet of the surface.

[a] Expressed by analyst in hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

Log of deep well No. 109 at Memphis, Tenn.

	Thickness.	Depth.
	Feet.	*Feet.*
Loess (45.4 feet):		
Yellow clay	27	27
Hard brown clay	10	37
Slightly soft brown clay	8.4	45.4
Lafayette (18 feet):		
Gravel and sand	4	49.4
Soft brown clay and sand	14	63.4
Lagrange formation (clay, 213 feet):		
Slightly hard brown clay	12.5	75.9
Stiff blue clay	3	78.9
Soft blue clay	4.4	83.3
Stiff blue clay	2.6	85.9
Soft brown clay	1	86.9
Hard brown clay	2	88.9
Hard reddish clay	1.5	90.4
Hard blue clay	15.5	105.9
Soft blue clay	15.1	121
Stiff blue clay	1	122
Soft brown clay	4	126
Rather hard brown clay	1.3	127.3
Stiff brown clay	1	128.3
Hard brown clay	8.7	137
Do	61	198
Rather hard blue clay	18	214
Hard blue clay	9	223
Sandy blue clay	53	276
Lagrange formation (sand, 724 feet):		
Fine sand and clay	27	303
Fine sand	35.4	338.4
Fine sand and lumps of clay	41.6	380
Coarse sand and lumps of clay	10	390
Soft blue clay	17	407
Sandy blue clay	10	417
Fine sand and clay	15	432
Sandy blue clay	42	474
Fine sand	2.6	476.6
Sandy blue clay	6.6	483.2
Fine sand	.8	484
Coarse sand and clay	6	490
Soft blue clay	2.3	492.3
Fine clay and sand	17.7	510
Very fine sand	25	535
Very fine sand and clay	38.2	573.2
Very fine sand	16.8	590
Very coarse sand	8	598
Lignite, iron pyrites, and clay	2	600
Very fine sand and lignite	195	795
Soft white clay	17	812
Very fine sand	53	865
Hard brown clay	31	896
Fine white sand	30	926
Hard brown clay	24	950
Fine sand	50	1,000
Porters Creek (Cretaceous) (147.55 feet):		
Stiff brown clay	25.6	1,025.6
Very hard substance	.5	1,026.1
Very stiff blue clay	121.4	1,147.5

This well was a failure, so far as obtaining a satisfactory flow of water was concerned, for the reason that no sand was found sufficiently coarse to be checked by the strainer. This unusual condition is sometimes encountered. Water flows more freely from coarse than from fine sand, and, furthermore, coarse sand is less likely to pass through the strainer than the fine, which seriously injures the pumping apparatus.

The Lagrange formation consists of intercalated irregular alternating lenses of sand and clay, the clay predominating above and the sand below. As a rule coarse sand is obtained in the Memphis district at depths of 350 to 560 feet. Generally the sand is finer above

and below this water-bearing layer. The water company is considering the question of sinking through the Porters Creek formation, which is mainly clay, into the Ripley below, which is a water-bearing sand. The following is a summarized section of the strata in this southern part of the embayment:

Strata in embayment region in western Tennessee.

	Thickness.
	Feet.
Loess	15- 27
Lafayette gravels	6- 40
Lagrange formation:	
Clay	150-200
Sand	800
Porters Creek clay, with supposed thin strata of limestone at bottom	250
Ripley sand	200-300
Selma clay	200-350
Eutaw sand	250

The last three members of this section belong to the Cretaceous. The Lagrange sands outcrop in the Tennessee hills east of Memphis and form the catchment basin for the greater part of this area. The main source of water in this belt is the bed near the middle or base of the Lagrange sands. The water here is very pure, while farther west and northwest it becomes less so, being impregnated with iron and, in some places, with sulphur. At Jackson, Miss., a stronger flow of still purer water was struck, which comes, it is stated, from the Ripley sands below the Lagrange. The engineers at Memphis are confident that a better quality and a stronger flow of water are characteristic of the Ripley.

It is interesting to note in the above summary the alternation of the impervious beds with the water bearers. The loess and the Lagrange, Porters Creek, and Selma clays alternate with the porous Lafayette gravel and Lagrange, Ripley, and Eutaw sands. It is stated that the water from the Eutaw is always impure. The water derived from these different formations is purer in proportion to the nearness of the well to the catchment basin.

MISSISSIPPI COUNTY, ARK.

The following analyses of water from shallow driven wells in Mississippi County, Ark., were furnished by Mr. W. B. Beckman, manager of the Chicago Mill and Lumber Company, of Blytheville, Ark. They are valuable in that they show the uniform character of the water throughout this part of the embayment region. The wells are located in sec. 9, T. 14, R. 9, at the foot of Big Lake.

Analysis of water from 30-foot well near Big Lake, Arkansas.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	40	Free ammonia	0.04
Iron and alumina oxides (Fe_2O_3+ Al_2O_3)	1.5	Albuminoid ammonia	.06
Calcium (Ca)	12	Nitrogen as nitrates	Trace.
Magnesium (Mg)	3.4	Nitrogen as nitrites	0
Sodium (Na)[b]	8.2	Chlorine as chlorides	7.26
Carbonate radicle (CO_3)	17	Oxygen consumed	2
Sulphate radicle (SO_4)	24	Appearance, good.	
Chlorine (Cl)	.7	Color, none.	
Loss, etc	.8	Odor, none.	
	113.9	Appearance of residue, white; no color on heating.	

This water is considerably better than the average for use in a steam boiler. It will, of course, deposit some scale, which is prone to be quite hard, etc. There is a very slight tendency to corrosion.

From a sanitary point of view the above analysis shows this water to be of a sufficient purity to warrant its use as a drinking water.

Analysis of water from 40-foot driven well near Big Lake, Arkansas.[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	38	Free ammonia	0.04
Iron and alumina oxides (Fe_2O_3+ Al_2O_3)	4.8	Albuminoid ammonia	.05
Calcium (Ca)	22	Nitrogen as nitrates	Trace.
Magnesium (Mg)	5.8	Nitrogen as nitrites	0
Sodium (Na)[b]	9	Chlorine as chlorides	7.26
Carbonate radicle (CO_3)	41	Oxygen consumed	1.8
Sulphate radicle (SO_4)	21	Appearance, slightly turbid.	
Chlorine (Cl)	7	Color, none.	
Loss, etc	1.6	Odor, none.	
	150.2	Appearance of residue, white; no color on heating.	

The action of the water when used in a steam boiler will be of the same nature as that from the 30-foot well, but the amount of scale formation will be about 38 per cent greater in quantity.

As regards the use of this sample for drinking purposes it is equally as good as the sample from the 30-foot well. While the sample is slightly turbid, it is due to a slight amount of mineral matter in suspension and in no way affects the quality. While the analysis shows a very slight difference, the two samples are virtually the same from a sanitary standpoint.

[a] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

[b] Sodium and potassium calculated as sodium.

TERRELL, ARK.

In sec. 29, T. 9, R. 8, is a well owned by the Baker Lumber Company. It was sunk in 1901 and cased with 6-inch casing to 86 feet and 4-inch casing to the bottom. The water, which is warm, rises within 12 feet of the surface. The following log was furnished by Mr. W. B. Johnson:

Log of well at Terrell, Ark.

	Thickness.	Depth.
	Feet.	*Feet.*
Alluvium and Lafayette (182 feet):		
"Buckshot," shading to sand	16	16
Orange sand and gravel, with thin clay partings	166	182
Lagrange formation (clay, 658 feet):		
Blue clay with enough fine sand to make sinking by hydraulic process easy; no water	658	840
Lagrange formation (sand, 24 feet):		
Gray sand, like that at Memphis; lignite in large quantities	24	864

When drilling in this well was stopped at 864 feet it was still in sand. The water has been analyzed and found excellent, with a little more iron than the Memphis water.

DRIFT-WELL DISTRICT.

Wells that obtain water from the drift are numerous in Iowa, Illinois, and the other Northern States, but have few representatives in Missouri, and these are almost entirely confined to the northwest corner of the State.

ATCHISON COUNTY.

TARKIO.

Tarkio is situated in the extreme northwestern part of the State, on Tarkio Creek. In May, 1890, a company was organized for the purpose of obtaining a city water supply, and later a number of wells were sunk in the district. The first one of these was put down at the edge of town, in sec. 14, T. 65, R. 40. Owner, Tarkio Water and Electric Light Company; depth, 210 feet; altitude above tide, 943 feet; casing, 8-inch; flow, strong; date of completion, May, 1890; driller, John Kain.

The following log of this well was furnished by Prof. J. C. Adair, of Tarkio College, to whom the writer is also indebted for the table of wells on page 190 and for partial water analyses, many of them made especially for this report.

Log of Tarkio Water and Electric Light Company well (No. 11), Tarkio, Atchison County.

	Thickness.	Depth.
	Feet.	*Feet.*
Black loam	30	30
Gray clay, with strata of glacial bowlders	40	70
Blue clay	100	170
Hardpan	10	180
Coarse sand	10	190
Rock	20	210

The water from this well flows in a stream from an 8-inch pipe 6 feet above the ground, and is conveyed to a reservoir 30 feet in diameter and 30 feet deep. Thence it is forced by a Dean surface pump, with a capacity of 1,000,000 gallons per day, to a standpipe 50 feet high and 12 feet in diameter, which stands on a hill 100 feet above the well. There is a normal pressure of 75 pounds from the standpipe and a fire pressure of 150 pounds. The well is also provided with a Cook deep-well pump of the same capacity. The water is hard, clear, and cold. The flow from the pipe varies a little, being not quite as strong now as it was at first. Other wells sunk at a lower level have to a slight degree lessened its head. A surface well 40 feet deep was also sunk by this company into the bowlder stratum given in the log. A feeble flow was obtained from this well, and the water is softer and better suited for boiler purposes. The population of Tarkio is 2,500, and it is estimated that the water supply is sufficient for a city of 10,000. At present the city uses about 150,000 gallons per day.

There seem to be two aquifers or water bearers in this district. The upper one varies from 7 to 10 feet in thickness and is usually found at a depth of 40 to 60 feet. It consists of either rounded bowlder material or gray, sharp, angular, coarse sand. The water from this bed is soft and is excellent for boiler use. The bed is usually overlain by 25 to 40 feet of yellow clay, forming the impervious layer.

The main water-bearing stratum and the one having the strongest pressure is a bed of 20 feet or more of sand which is made up of rounded grains and is called the "artesian sand." This is overlain by an impervious layer of dark-blue clay from 140 to 160 feet thick, the lower half of which contains small round pebbles the size of walnuts and numerous pockets of sand.

Tarkio Valley is from 2 to 3 miles wide and is inclosed by low, rounded hills which rise from 50 to 100 feet above Tarkio Creek, a rapid stream that frequently overflows its low banks. The channel has been straightened through the town, where it is confined to a deep ditch running between dikes, which partially control the floods. When visited in July, 1904, the whole valley was sodden with water

as a result of long-continued rains. The cornfields were swamps, although miles of drainage tiles had been laid through them. This condition certainly suggests that the water must rise from the first sand layer under such pressure as to keep the land unusually damp.

Fig. 6 shows the location of the wells referred to in the accompanying table. They extend for a distance of 14 miles, beginning 5 miles north of Tarkio and continuing for 9 miles south, to Fairfax. Mr. James Chambers, who has sunk some wells in this region, states that there is apparently an ancient buried channel in this valley and that the flow in this channel is from the northwest. He has noted that in sinking wells on the extreme sides of the valley only 2 or 3 feet of the "artesian sand" were passed through, while nearer the center of the valley this sand layer is 40 or more feet thick. Mr. Chambers states that in drilling these wells he uses an auger and that frequently good veins of water are found in the yellow clay. If such a vein is tapped there is no necessity of going deeper, as a shallow well of living water is thus assured. Wells bored in this way are quickly and cheaply obtained, 80 to 90 feet being the maximum day's work.

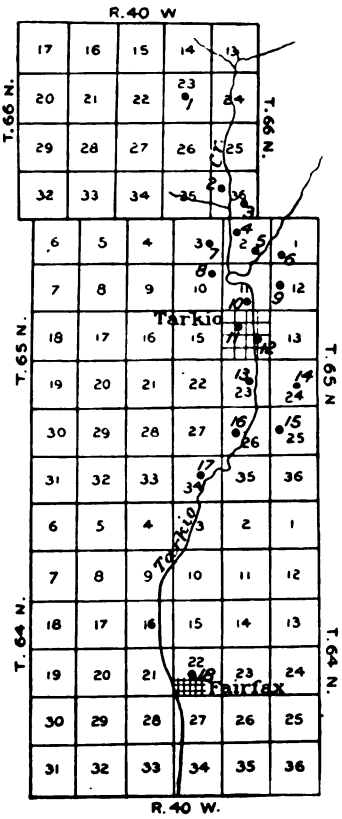

FIG. 6.—Map showing location of the Tarkio artesian wells, Atchison County.

The following is the log of well No. 17, a salt well:

Log of Rankin well (No. 17), Tarkio, Atchison County.

	Thickness.	Depth.
	Feet.	*Feet.*
Black loam	30	30
Gray clay, with occasional strata of loose bowlders	40	70
Blue clay	110	180
Hardpan, white	15	195
Gravel, water bearing	10	205
Carbonaceous shale, with considerable lignite	15	220
Rock; stopped before going through it	50	270

This well contains 5,400 parts of chlorine per million, while well No. 11, 2 miles to the north, gave only 111 parts, and Nos. 15 and 16, a little over a mile to the northeast, 128 and 120 parts, respectively. Well No. 18, at Fairfax, is also a salt well, with about 5,400 parts of chlorine per million, or about 3 ounces of salt to the gallon.

The accompanying table, prepared by Prof. J. C. Adair, gives condensed data in regard to the wells of this district:

Statistics of well in Tarkio district, Atchison County.

No. in fig. 6.	Owner of land.	Driller.	Location.			Elevation of well mouth (feet).	Date drilled.	Depth (feet).	Flow (gallons per minute).	Height of water above surface (feet).	Partial analysis (parts per million).					
			Township.	Range.	Section.						Total solids.	Chlorine.	Free ammonia.	Albuminoid ammonia.	Temporary hardness.	Permanent hardness.
1	B. J. Jones	R. C. Van Leuvan	66	40	23	933	1894									
2	D. West	do	66	40	36	925	July, 1894	130	1			106	6.2	5	243	405
3	E. Lindstrom	do	66	40	36	925										
4	D. O. Murphy	do	65	40	2	921			1							
5	R. C. Van Leuvan	do	65	40	2	920	July, 1901	140	1½			162			287	340
6	A. Smith	do	65	40	1	920		140								
7	Stevenson & McPherson.	do	65	40	3	925	1893	145	2			106			233	516
8	G. D. Gordon		65	40	10	917						152			41	455
9	A. Craig		65	40	12	915		148								
10	D. Rankin	John Kain	65	40	11	915	1891	165	1½			118	8	4	122	506
11	Tarkio Water and Electric Light Co.	do	65	40	14	943	May, 1890	210			1,442	111	8	10	259	367
12	Dr. S. R. Andes	R. C. Van Leuvan	65	40	14	913			2			118	8	5	157	501
13	D. Rankin	John Kain	65	40	23	905	May, 1891			32						
14	W. S. Wood	R. C. Van Leuvan	65	40	24	905		175								
15	P. McKenzie	Jas. Chambers	65	40	25	901		170	1½	20		128	1	1.5	203	379
16	D. Rankin	John Kain	65	40	26	900	Sept. 1890	170	1			120			202	367
17	do	—— McIntosh	65	40	34	896	Mar. 1891	220	1	40	9,753	5,400	5.2	5	298	688
18	W. P. Green		64	40	22	876	June, 1891					5,400				
19	Tarkio Water and Electric Light Co.[a]	John Kain				943		40	1½			1.6		.06	142	40

[a] Surface well; used for boiler supply, also by laundries.

The diameter of all these wells is 3 inches, with the exception of No. 11, which is 8 inches. The temperature of the water is 12° C. Several of the wells flowed for a short time, but when others were put down they ceased to flow and are now being pumped. The depth to the "artesian sand" seems to increase to the south. In well No. 14, in the extreme eastern part of the basin, rock was reached without finding the sand. To the west the surface is much higher, and though the sand is reached the wells do not flow. Seven miles west of Tarkio, at Rockport, a well was drilled to a depth of 700 feet without finding water. It is probable that the western side of the buried channel is but a few miles west of Tarkio Creek. This ancient channel was undoubtedly cut during the extension and retreat of one of the great northern ice sheets. The vast quantity of water set free by the melting front of this ice sheet found its outlet through the valleys toward the south, in which they left their load of sand and gravel. These deposits were in turn covered by impervious clays from the moraines of subsequent ice sheets, a condition which probably occurred more than once.

Professor Adair has called attention to the large amount of ammonia, both free and albuminoid, contained in the waters of these wells. It is also interesting to note the great variation in the composition of water in wells very near to each other, a fact to which attention has already been called. A series of partial analyses made by Professor Adair shows a constant variation of ammonia in the same well during a period of years. So excessive an amount of albuminoid ammonia as is contained in some of these wells would ordinarily condemn the water at once as being subject to sewage contamination; but there could be no possibility of such contamination in this district, and it is a well-established fact that many other drift wells contain large amounts of this substance. Norton[a] mentions its occurrence in the waters of the drift wells of Iowa, and suggests several theories for its presence. One of these theories is that these artesian waters were originally storm and surface waters, which have taken ammonia from the atmosphere and soil and kept it imprisoned in these basins. Another and a more probable hypothesis is that the ammonia originated from the decomposition and breaking up of the fossil organic remains contained in these sedimentary deposits. Just as the ammonia of commerce is manufactured from the products resulting from the distillation of coal, so it is possible that the ammonia in the water may be derived from the nitrogen of the lignite and carbonaceous shales which are so often present in the drift—a view which, according to Norton, is supported by the association of the ammonia with the hydrogen sulphide of these waters.

[a]Norton, W. H., Artesian wells of Iowa: Ann. Rept. Iowa Geol. Survey, vol. 6, 1897, pp. 358-361.

A well not far from the salt well at Fairfax is highly charged with iron and sulphur.

HOLT COUNTY.

MOUND CITY.

In sec. 29, T. 62, R. 38, on the farm of James A. Vandeventer, is a shallow well flowing about 3 gallons per minute, with no apparent variation. The water is clear, cold, and soft, with some iron, and leaves a reddish coating on pipes and ground. It is derived from a sand layer under a blue clay. It is highly esteemed as a chalybeate water. An artificial lake and a grove of native forest trees render the locality of the well an attractive pleasure ground.

CITY WATER SUPPLIES.

GENERAL DISCUSSION.

SOURCE OF SUPPLY.

The tendency toward the concentration of population in cities and towns has caused a growth that has outdistanced all calculations made when most waterworks systems were originally established. Moreover, the increase in the per capita use of water has been very great and cities are everywhere forced to seek new sources of supply. Lakes, rivers, and springs have heretofore been the main dependence; but these are so generally becoming polluted by sewage, manufacturing wastes, and in other ways, that the problem of pure water is yearly more and more serious.

This problem is more difficult of solution for the larger cities because of the thickly settled districts which surround them. New York City consumes 340,000,000 gallons of water per day. An increase in population of 100,000 per year, which has been the case for the last decade, means necessarily a large addition to the water supply in order to keep pace with such tremendous growth. This city is now looking to the Catskill Mountains as apparently the only available source from which the present supply can be increased. To bring the water of this distant region to the doors of the New York consumers will entail an expenditure of $150,000,000. The present system has already cost $100,000,000.

The problem is even more serious for some foreign cities. Paris has for many years taken from the Seine water for all purposes, but now finds it suitable for street sprinkling and industrial uses only. Other cities of France have secured control of all the available mountain lakes and streams, leaving the capital to contemplate the advisability of establishing filtration plants to make possible the use of the sewage-laden river water.

Many cities, apparently ideally located so far as water supply is concerned, have difficulties to overcome. Chicago, for example, situated on a great fresh-water lake, has had to expend millions of dollars, not only in extending the intake of its water supply farther into the lake, but also in building a great drainage canal to carry into the Mississippi River the sewage that would otherwise pollute the water.

Cleveland has been compelled to go far toward the center of Lake Erie for an intake free from pollution. Philadelphia, procuring water from Delaware and Schuylkill rivers, which are badly polluted, as is shown by the epidemics of typhoid fever so common in that city, is now planning to spend $20,000,000 in the construction of a sand filtration plant for the purification of this water.

London, England, has under consideration a project for bringing from Wales water sufficiently pure for drinking purposes, and Manchester obtains its supply from the lakes of Scotland.

Many southern cities are largely dependent on cisterns for water for domestic purposes. These cisterns are open to contamination from many sources and can not be considered suitable for a permanent supply.

ARTESIAN WATER AS A SOURCE OF SUPPLY.

As a knowledge of the dangers existing in natural water supplies is more widely disseminated, the advisability of seeking in deep wells a source of city water is being more seriously considered. Some degree of uncertainty is connected with the sinking of such wells, not only as regards the quantity of water to be obtained, but also with respect to the quality. Both of these questions are geologic in their nature and can be intelligently considered only in the light of a knowledge of the structure of the rocks which underlie the region and of the nature of the water which characterizes the different geologic formations. It is one purpose of this report to show, so far as available knowledge of the stratigraphy and geologic structure of Missouri goes, the possibility of obtaining in various localities not only flowing wells, but also a sufficient quantity of wholesome water from deep, nonflowing wells.

The city of Memphis, Tenn., has solved its own water problem in a highly satisfactory manner. Formerly having one of the highest death rates in the country, and frequently visited by terrible epidemics of cholera and yellow fever, it is now one of the healthiest cities in the United States; and it is not saying too much to claim that this new sanitary condition is largely the direct result of the development of a magnificent system of artesian wells.

CHARACTERISTICS THAT AFFECT THE VALUE OF WATER FOR PUBLIC SUPPLY.

The value of water for a public supply may be discussed under tw heads: (1) Its potability; (2) its suitability for domestic and ma ufacturing purposes.

POTABILITY.

A drinking water may be injurious from two causes—from t amount of injurious mineral constituents, and from pathogenic be teria. A good drinking water should be clear and palatable, a should not have an excess of such mineral matter as the salts of li and magnesia, which are claimed by many to produce or aggravate se diseases as rheumatism, urinary calculi, goiter, and cretinism. T best authorities recommend the avoidance of very hard waters people over fifty years of age. The presence of iron gives a pecul taste to the water, which is in such cases known as chalybea While this is not injurious to health, except when the iron is in exc of 1 part per million, and is often considered beneficial as a mine water, it is objectionable for a public supply and general use b because of the taste and the fact that, on standing, a precipitate u ally forms that discolors the water and the containers.

Whatever difference of opinion may exist in regard to mineral im rities, there can be no dispute concerning the danger connected w organic impurities existing as a result of contamination from sew and many other sources. It must be made clear, however, tha not the dead organic matter or sewage that renders the wate gerous, but the living pathogenic bacteria that can thrive o waters containing such impurities. Typhoid fever, for exa often has its source in the use of polluted water. This is also b to be true, to a large degree, of such diseases as cholera and dys Abundant statistics could be given relating to the great decre these diseases in cities that have changed from a polluted to a water supply.

Great care should be taken of the water after it is derived fro ground, particularly in the reservoir, where it is stored to awa tribution. A standpipe is far better than an open reservoir for a purpose. The latter is liable to become infected by dust, intrusion of animals, and by depredations committed by thoug or malicious individuals. Even the standpipe is not wholly fro contamination unless properly protected. As an illustration of it may be stated that after an outbreak of typhoid fever in one cities of a neighboring State, it was discovered that while the at its source was pure, the tap water contained typhoid bac investigation of the standpipe, which was over 100 feet high, the fact that it contained an accumulation of over 2 feet of

English sparrows that had flown against the inner wall and had drowned. All standpipes should be covered with wire gauze to prevent similar pollution.

HARDNESS.

For domestic supply water should not be too hard—that is, it should not contain too large an amount of the salts of lime, magnesia, and iron. If such is the case, it is objectionable for cooking purposes. Very hard waters are said to affect the taste of foods cooked in them. If too much iron is present, it unites with the tannin of tea and coffee to form a black precipitate. An excess of iron is also objectionable for laundry use, as it is likely to form rust spots on clothing. But one of the most serious objections to hard water from the standpoint of domestic use is the large amount of soap that it requires to produce a lather. Turneaure and Russell,[a] quoting from Parks, state that the city of Glasgow, Scotland, saves $180,000 annually in the cost of soap used since the introduction of the soft water from Loch Katrine as a city supply. Soap is a combination of soda with some of the fatty acids. Pure water, such as rain water, dissolves soap perfectly and forms a lather at once. But water containing certain mineral salts in solution—notably the carbonates and sulphates of lime, magnesium, and iron—does not do this, because these salts form insoluble precipitates with the soap. If it takes a great deal of time to produce a lather with soap, the water is hard, and it will be seen that the amount of soap required before the water will lather gives a test of the relative amount of salts which cause the hardness of the water.

That quality of water called "hardness" is usually referred to as "total," "temporary," and "permanent," the last being, perhaps, the most important of the three, since it represents the sulphates, chlorides, and nitrates of lime and magnesia. By "total hardness" is meant the natural hardness of the water—that is, the aggregate amount of earthy salts and free carbon dioxide. The "temporary hardness" is that which disappears on boiling, and the "permanent hardness" is that which is unaffected by boiling. Clark's scale of hardness is expressed in degrees, 1° being equivalent to the hardness produced by 1 grain of calcium carbonate per gallon. In American practice the hardness is expressed in terms of parts of calcium carbonate per million. To convert degrees of hardness to parts per million, multiply by 14.3. In a general way, if a water has a total hardness of less than 85 parts per million, it is soft; at 115 parts per million it is moderately hard; at 230 parts per million it is very hard, and above that it is objectionable.

The waste of soap and extra labor entailed by the use of very hard water make the subject of hardness of very great importance. Every

[a] Turneaure, F. E., and Russell, H. L., Public Water Supplies, 1901, p. 143.

harder matter deposited on boilers from the decom
mineral salts. The term "sludge," or "mud," is a
or loose precipitates, such as calcium and magn
These form the temporary hardness of water and ar
more easily removed from boilers than the scale, wh
permanent hardness and is made up mainly of calciu
sulphates. This scale involves considerable loss of
mated that an incrustation one-sixteenth of an inch
conductor of heat, causes a loss of energy of 15 to
coal used. Waters that have a temporary hardnes
scale that may be blown out; while those that have
hardness form a scale which can be removed only wi
This scale not only results in the loss of energy, bu
the iron and is frequently the cause of boiler expl
estimates that the extra expense due to the use of l
railway engines of the Middle and Western States
$750 per year for each engine.

At a session of the American Association of Ra
Buffalo, N. Y., in 1887, a system of rating for boil
gested, which, as slightly modified by Norton,[b] is as

Ratings for boiler waters.

Rating.

The problem of scale is very serious and many methods of obviating this difficulty have been proposed.[a] A careful quantitative analysis must always be made to determine the nature of hard water and the treatment necessary to render it suitable for use. In some cases waters that contain a large amount of scale-forming material carry also enough alkaline salts to supply their own remedy. In Oklahoma, as reported to the writer by Mr. C. D. Purdon, engineer of maintenance of way of the Frisco System, the water used to supply one tank contains a large amount of scale-producing salts, while that of another but a few miles distant contains the remedy for them, and a mingling of the two waters produces results so good that engineers find no difficulty in their use.

The mineral salts that occur in water and that are objectionable in the manufacture of steam are described in the following paragraphs:

Calcium carbonate is the most common form in which lime occurs. It is but slightly soluble in distilled water, but when carbon dioxide is present, as is generally the case, it is easily soluble and forms lime bicarbonate. Heat decomposes this lime bicarbonate in boilers, driving off the carbon dioxide and precipitating the lime. This forms a scum on the water which prevents the free escape of steam and, if in excess, frequently causes "foaming." It is also precipitated in the form of scale, some of which is carried by the steam into the piston and cylinders, where it has a most injurious effect. The lime does not form a hard scale unless mixed with other salts which cement it to the sides and flues of the boiler.

Calcium sulphate forms the hardest scale known, sometimes almost as hard as porcelain. When the boiler pressure is at 50 pounds, this substance is almost entirely precipitated from the water.

Calcium chloride is occasionally present in water. It does not form scale, but is highly corrosive. If lime or magnesium sulphates are present, under heat and pressure an interchange of acids takes place and calcium or magnesium sulphates, which do form a scale, are produced.

The action of magnesium carbonate is similar to that of calcium carbonate, but only the magnesium bicarbonate is soluble. It is a fine nonconductor of heat, for which reason it is frequently used on the outside of boilers and pipes.

Magnesium chloride is frequently present in water and, if in considerable amounts, is very injurious. At 310° F. it is decomposed, reacting, with water, to form magnesium oxide and hydrochloric acid, which latter corrodes the boiler, especially at the water line. Allen states that certain amounts of sodium chloride may prevent

[a] An excellent article on this subject is given by Turneaure, F. E., and Russell, H. L., Public Water Supplies, 1901, p. 481.

this decomposition, the two chlorides uniting to form a stable d
salt. Norton[a] says:

In contact with boiler plates, calcium and magnesium carbonates of the sc
changed to caustic oxides by the intense heat, and, according to Lewes, if magn
chloride is present the same result may be reached by reaction with calcium c
ate. So long as heated these oxides remain anhydrous, but are changed to hydra
access of water on cooling.

A small amount of magnesium chloride, even a grain or two t
gallon, is considered objectionable in boiler waters.

Magnesium sulphate is one of the most soluble of all the mi
salts. In itself it does not produce scale, but when superheat
the presence of other lime salts it breaks up, and new and inju
combinations are produced.

Sodium sulphate and sodium chloride are not scale produ
but are liable to produce "foaming" when present in large amo
The same is true of sodium carbonate. Sodium chloride is l
corrosive.

Iron bicarbonate, having a weak hold on the carbon dioxi
easily decomposed and forms ferrous oxide, which, uniting wit
gen and water, forms the hydrated sesquioxide, the yellow p
tate commonly noticed in chalybeate waters. Iron sulph
frequently present in waters that have their source in the Pe
vanian rocks, and it is very corrosive in boilers.

The presence of carbon dioxide, ammonia, nitrates, and s
probably objectionable, but how much so has not been fully
mined. Some of these, especially the nitrates, are, wither
corrosive when present in large amounts.

Silica usually occurs in so small amounts as to be of lit
tance in this connection.

CITY WATER SUPPLIES IN MISSOURI.

STATISTICS

The accompanying tables give a list, as complete as it is
possible to make, of the 103 cities and towns in Missouri tha
public water supply, with statistics relating to each and an
many of the waters. In connection with the capacity of the
systems, it is interesting to note the daily consumption in
cities and the possibilities of providing for future needs.

In preparing these tables, the writer has supplemented
notes by reference to Baker's Manual of American Wat
The following table gives the per capita consumption of the
cities in the world.

[a] Norton, W. H., Artesian wells of Iowa. Ann. Rept. Iowa Geol. Survey, [illegible]

Daily per capita consumption of water in various cities.

	Gallons.		Gallons.
Paris	37	Brooklyn	90
London	45	New York	125
Berlin	50	Chicago	180
Kansas City	80	Philadelphia	236

In calculating the amount of water necessary for a city supply, at least 100 gallons per capita per day should be estimated. In artesian districts it is very easy to estimate either the flow or the pumping capacity of wells. Norton[a] suggests that where a number of wells are sunk, they should be aligned at right angles to the dip of the water-bearing strata, so as to tap a larger area. The distance between flowing wells should be as great as is consistent with the other factors considered in their disposition. If the flow is weak, "shooting" will frequently increase the pressure.

[a] Norton, W. H., Artesian wells of Iowa: Ann. Rept. Iowa Geol. Survey, vol. 6, 1897, p. 410.

Statistics of city waterworks in Missouri. [a]

City.	County.	Population (1900).	Source.	Date established.	Cost.	System.	Pressure. Ordinary.	Pressure. Fire.	Reservoir capacity.	Standpipe capacity.	Length of mains.	Daily consumption.	Remarks.
							Pounds	*Pounds*	*Gallons.*	*Galls.*	*Miles.*	*Gallons.*	
Albany	Gentry	2,025	Well			Direct pressure							
Aurora	Lawrence	6,191	Spring	1892	$79,000	Steam pumps	45	110		132,000	14¾	250,000	Analysis 1.
Bethany	Harrison	2,093	Creek	1894	30,000	Pump to standpipe				84,000	4		
Bolivar	Polk	1,869	2 springs	1894	11,267	Pump							
Bonneterre	St. Francois	4,500	Big run	1887		Direct pumping							
Booneville	Cooper	4,377	Missouri River	1883	89,500	Pump to reservoir and standpipe; gravity.	40–65	60–85	6,250,000	60,000	8	250,000	
Bowling Green	Pike	1,902	Well			Gravity							Analysis 2.
Brookfield	Linn	5,484	Open well	1890	33,500	Pump to standpipe and direct pressure.	60	100		93,000	8	40,000	Analysis 3.
Brunswick	Chariton	1,403	Grand River	1894	13,500	Pump to standpipe and direct.	70	150		29,000	1½	20,000	
Butler	Bates	3,158	Miami Creek	1891	75,000	Pump to reservoir and standpipe and direct.	40	130	2,000,000	115,000	6	30,000	
Cameron	Clinton	2,979	Pond for drainage.			Pump to standpipe							
Canton	Lewis	2,365	Artesian well			Gravity							Analysis on p. 46.
Cape Girardeau	Cape Girardeau.	4,815	Mississippi River.	1895		Pump to reservoir			1,200,000		7.3		
Carrollton	Carroll		Driven well	1888	30,000	Pump to standpipe and direct.	80	130		93,000	2½		Analysis 4.
Carterville. [b]													
Carthage	Jasper	9,416	Spring River	1882		Pump to standpipe and direct.	40	118		182,000	14		Analysis 5.
Caruthersville	Pemiscot	2,315	Deep well	1903	26,000	do							Analysis on p. 178.
Charleston	Mississippi	1,893	Driven well										
Chillicothe	Livingston	6,905	River and wells	1887	225,000	Pump to standpipe and direct.	65	100		126,000	13	500,000	Analysis 6.
Clarence	Shelby	1,184	Well										
Clinton	Henry	5,061	Artesian wells	1886	93,000	Pump to standpipe and direct.	75	150	2,800,000		7½	275,000	Analysis on p. 117.
Columbia	Boone	5,651	Ponded creek	1893		Pump direct from ponded reservoir.							
Commerce	Scott	588	Springs, wells			Windmill, tanks, and mains.							
Concordia	Lafayette	889	Well			Standpipe							
De Soto	Jefferson	5,611											
Dexter	Stoddard	1,892	Well			Windmill and direct pressure.							

Eldorado Springs	Cedar	2,137	Deep well			Pump							
Excelsior Springs	Clay	1,881	River	1892		Filter and pump to reservoir.							Analysis 7.
Farmington	St. Francois	1,778	Deep well										
Fayette	Howard	2,717	Deep well (not used.)			Pump to standpipe; system of shallow wells being developed.							
Ferguson	St. Louis	1,015	Missouri River	[c]1903									
Fulton	Callaway	4,883	Artesian wells	1889		Gravity to reservoir and direct pumping.	75	150	132,000	109,000	3.7	30,000	Analysis 8.
Gallatin	Daviess	1,780	Well			Pump to standpipe							
Glasgow	Howard	1,672	Missouri River	1895	10,000	Pump to standpipe and direct.	45	82		40,000	1	20,000	
Granby	Newton												
Grant City	Worth	1,406	Well	1896	7,500	Pump to tank	40	140		30,000	1	5,000	
Hannibal	Marion	12,780	Mississippi River	1880	172,000	Pump to reservior	25	100	17,500,000		15½		
Hermann	Gasconade	1,575											
Higbee	Randolph	1,151											
Higginsville	Lafayette	2,791	Deep well	1891	15,000	Pump to reservoir and direct.	55	125	80,000		1½	25,000	Analysis 9.
Holden	Johnson	2,126	Ponded reservoir.	1887	65,000	Pump to standpipe and direct.				75,000		50,000	
Huntsville	Randolph	1,805											
Independence	Jackson	6,974	Missouri River	1884	100,000	Pump to settling basin and thence to standpipe.	50	100	1,000,000	250,000	8½	250,000	
Jackson	Cape Girardeau.	1,658	Pearl River			Standpipe and direct.							
Jefferson City	Cole	9,664	Missouri River	1888	140,000	Pump to reservoir and thence to standpipe.	70	125	2,400,000	300,000	8	450,000	
Joplin	Jasper	2,623	School Creek	1880	185,000?	Pump to reservoir and direct.	30	110	3,000,000		24		Analysis 10.
Kahoka	Clark	1,818	Deep well (509)	1902 1873	3,000?	Direct pressure	40	100	75,000				Well in sandstone.
Kansas City and Westport.	Jackson	163,752	Missouri River		3,000,000?	Pump to reservoir	130	175			138.7	11,000,000	
Kirksville	Adair	5,966	Deep well (1,300 feet) and Chariton River.	1894	60,000	Pump to reservoirs and repumping direct.	40	100	145,000		4½	40,000	Analysis 11.
Kirkwood	St. Louis	2,825	Missouri River	[d]1903		Pump to standpipe							
Lamar	Barton	2,737	Creek			do							
Lebanon	Laclede	2,125	Artesian well (1,000).	1890		do				85,000			Analysis 12.
Lexington	Lafayette	4,190	Missouri River	1885	100,000?	Pump to settling tanks and thence to standpipe.	65	120	2,000,000	350,000	7	228,000	

[a] This table has been compiled from notes obtained by the writer from Baker's Manual of American Waterworks and from Missouri Geological Survey reports.
[b] See Webb City.
[c] Incomplete.
[d] In progress.

Statistics of city waterworks in Missouri—Continued.

City.	County.	Population (1900).	Source.	Date established.	Cost.	System.	Pressure. Ordinary.	Pressure. Fire.	Reservoir capacity.	Standpipe capacity.	Length of mains.	Daily consumption.	Remarks.
							Pounds	*Pounds*	*Gallons.*	*Galls.*	*Miles.*	*Gallons.*	
Louisiana	Pike	5,131	Mississippi River	1888		Pump to reservoir and direct gravity.	120		2,000,000		6		
Macon	Macon	4,068	Chariton River	1891	30,000	Direct pumping from ponded reservoir.	60	125	60,000,000		3 ½		
Malden	Dunklin	1,462		a1897									
Marshall	Saline	5,086	Wells	1885	85,000	Direct pumping	65	130			5	275,000	Analysis 13.
Maryville	Nodaway	4,577	One Hundred and Two River.	1886	140,000	Pump from river to reservoir and thence to standpipe and direct gravity.	60	120	20,000,000	120,000	9 ½	287,671	
Memphis	Scotland	2,195	Well and creek		13,000	Pump to standpipe				78,000			
Meramec Highlands	St. Louis	110	Meramec River	1893		Pump to tank and direct.	30	100		16,000	1 ¾		
Mexico	Audrain	5,099	Artificial lake and deep well (1,000 feet).	1885	80,000	Pump to reservoir and direct.	50	100	50,000,000		5	400,000	Analysis on p. 73; water in sandstone at 1,000 feet.
Moberly	Randolph	8,012	Ponded creek and two deep wells (500 feet).	1885	100,000?	Pumps			250,000,000		6 ¾	410,000	Analysis 14.
Monett	Barry	3,115	Well	1892	15,000	Standpipe							Analysis 15; well supposed to intercept subterranean stream.
Montgomery City	Montgomery	2,026	Deep well			Pump to tank							
Mound City	Holt	1,681	Wells		14,000	Pump to standpipe	30			35,000	2		
Mount Vernon	Lawrence	1,206	Spring	1897	15,040	do							
Neosho	Newton	2,725	Elm Springs	1891	50,000	Gravity system	50	60			12		
Nevada	Vernon	7,461	Deep wells and Marmaton River.	1885	150,000?	Pump to reservoir and direct.	23	150	2,000,000		26	700,000	Analysis 16.
Oregon	Holt	1,032	Well		22,000	Pump to tank							Analysis 17.
Osceola	St. Clair	1,037	Osage River			Pump to tower and tank.							
Ozark	Christian	830	Spring										
Pacific	Franklin	1,213	Meramec River		b 15,000				500,000				Proposed.

Palmyra	Marion	2,323	Spring	1891	50,000	Pump from reservoir and standpipe direct.	90	140		100,000	4		
Paris	Monroe	1,397	Salt River		23,000	Standpipe and direct pressure.							
Parkville	Platte	931	Missouri River										
Pierce City	Lawrence	2,151	Spring	1888	45,230	Gravity to standpipe.							
Poplar Bluff	Butler	4,321	Black River	1895	25,000	Pump to standpipe				158,000	4	60,000	
Princeton	Mercer	1,575	Well	1896	16,500	do				42,000			
Rich Hill	Bates	4,053	River	1883	130,000?	Pump from river to well and direct pumping.					10	240,000	
Richmond	Ray	3,478	Driven wells	1897	42,102	Pump to reservoir and standpipe.	60		80,000	118,000	8.4		
Rockport	Atchison	1,080	Deep well	1892	17,000	Pump to standpipe	80			39,000		10,000	
St. Charles	St. Charles	7,982	Missouri River	1881	80,000	Pump to settling tanks and thence to standpipe and direct.				250,000	7 ½		
St. Joseph	Buchanan	102,979	do	1880		Pump to reservoir	120		16,000,000		63		Analysis 18.
St. Louis	St. Louis	575,238	Mississippi River	1831	13,345,000	Reservoirs and standpipes.	5	75	65,000,000	63,000	462	55,000,000	
Sedalia	Pettis	15,231	Artesian wells	1871	578,000	Pump to standpipe and to reservoir.	56?			364,000	34	1,500,000	Analysis on p. 98.
Slater	Saline	2,502	Deep well (650 feet).		20,000								Analysis 19.
Springfield	Greene	23,267	Spring	1883	475,000	Pump to reservoir and tanks.			4,000,000	750,000	57 ½	2,500,000	Analysis 20.
Stanberry	Gentry	2,654		1893		Pump					3 ½		
Sullivan	Franklin	714	Spring			Pump to water tank				30,000			
Sweet Springs	Saline	1,080	Deep well			Tower, tank, gravity							
Tarkio	Atchison	1,901	Artesian well	1891		Pump to standpipe and direct.	70	120		42,000		50,000	Analysis 21.
Trenton	Grundy	5,396	Grand River and wells.	1886	78,200	do	60	130		317,000	7		Analysis 22.
Union	Franklin	744	Bombois River	1896	10,000	Pump to reservoir and direct.	60	100	175,000		2 ½		
Unionville	Putnam	2,050	Pond	1897	15,000	Direct pressure							
Verona	Lawrence	750	River	1894	30,000?	Pump to standpipe							
Warrensburg	Johnson	4,724	Springs	1894	150,000?	do						8,000	Analysis 23.
Washington	Franklin	3,015	Missouri River	1889	65,000	Pump to settling reservoir and thence to standpipe and direct.	70	100	125,000	105,000	4 ½	75,000	
Webb City and Carterville.	Jasper	9,201 4,445	Springs	1890	150,000	Gravity to well and then pumped to standpipe.	45	75		125,000	21	500,000	Analysis 24.
Webster Grove	St. Louis	1,895	Well	1891	(c)	Pump to tank							
Westport[d]	Jackson			1890									
Willow Springs	Howell	1,078	Deep well		16,000	Pump to tank	20	40		67,000	3		

[a] Open for bids. [b] Estimated. [c] In Kansas City system. [d] In progress.

ANALYSES OF WATERS OF PUBLIC SUPPLIES.

ANALYSIS 1.—*Aurora city water, January 15, 1904.*[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	8.2	Residue on evaporation	100
Iron (Fe)	.86	Residue on ignition	91.8
Aluminum (Al)	.08	Free ammonia	.16
Calcium (Ca)	54	Albuminoid ammonia	.15
Magnesium (Mg)	2.5	Nitrogen as nitrates	.23
Sulphate radicle (SO_4)	26	Nitrogen as nitrites	0
Chlorine (Cl)	3.5	Oxygen consumed	3.04
		Color, very clear.	
	95.14	Odor, none.	

ANALYSIS 2.—*Bowling Green city water, January 17, 1904 (partial analysis).*

	Parts per million.		Parts per million.
Silica (SiO_2)	4	Residue on evaporation	572
Iron (Fe)	1.6	Residue on ignition	409
Aluminum (Al)	.37	Free ammonia	.08
Calcium (Ca)	114	Albuminoid ammonia	.15
Magnesium (Mg)	36	Nitrogen as nitrates	12
Sulphate radicle (SO_4)	48	Nitrogen as nitrites	Trace.
Chlorine (Cl)	49	Oxygen consumed	2
		Color, clear.	
	252.97	Odor, none.	

ANALYSIS 3.—*Brookfield city water (open well), March 12, 1904.*[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	17	Residue on evaporation	417
Iron (Fe)	1.9	Residue on ignition	396
Aluminum (Al)	.15	Free ammonia	.12
Calcium (Ca)	6.8	Albuminoid ammonia	.22
Magnesium (Mg)	14	Nitrogen as nitrates	.5
Sulphate radicle (SO_4)	59	Nitrogen as nitrites	.018
Chlorine (Cl)	17	Oxygen consumed	3.2
		Color, none.	
	115.85	Odor, none.	

ANALYSIS 4.—*Carrollton city water, April 7, 1904.*[a]

	Parts per million.		Parts per million.
Total residue after evaporation	450	Nitrogen as nitrates	0.35
Oxygen consumed	7.95	Nitrogen as nitrites	.05
Free ammonia	.24	Color, slightly amber.	
Albuminoid ammonia	.18	Odor, none.	

ANALYSIS 5.—*Carthage city water, March 7, 1904.*[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	16	Residue on evaporation	178
Iron (Fe)	2.4	Residue on ignition	166
Aluminum (Al)	.1	Free ammonia	.05
Calcium (Ca)	50	Albuminoid ammonia	.17
Magnesium (Mg)	4.2	Nitrogen as nitrates	.63
Sulphate radicle (SO_4)	25	Nitrogen as nitrites	.007
Chlorine (Cl)	4.2	Oxygen consumed	2.9
	101.9		

[a] Bull. Missouri State Board of Health, vol. 1, No. 4, 1904. Recomputed to ionic form at United States Geological Survey.

ANALYSIS 6.—*Chillicothe city water, February 6, 1904.*[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	20	Residue on evaporation	183
Iron (Fe)	6.1	Residue on ignition	166
Alumina (Al)	.14	Free ammonia	.24
Calcium (Ca)	3.6	Albuminoid ammonia	.33
Magnesium (Mg)	6.8	Nitrogen as nitrates	.26
Sulphate radicle (SO_4)	26	Nitrogen as nitrites	.055
Chlorine (Cl)	5	Oxygen consumed	7
		Color, slightly turbid.	
	67.64	Odor, none.	

ANALYSIS 7.—*Excelsior Springs city water (river).*[b]

	Parts per million.		Parts per million.
Silica (SiO_2)	22	Free ammonia	.02
Iron and alumina oxides (Fe_2O_3+ Al_2O_3)	3.5	Albuminoid ammonia	.07
Calcium (Ca)	85	Nitrogen as nitrates	Trace.
Magnesium (Mg)	7.7	Nitrogen as nitrites	Trace.
Sodium (Na)[c]	6.8	Chlorine as chlorides	53.05
Carbonate radicle (CO_3)	115	Oxygen consumed	3.1
Sulphate radicle (SO_4)	50	Color, somewhat turbid.	
Chlorine (Cl)	11	Odor, none.	
	301		

This river water is filtered through a layer of coke 5 feet thick, then through 28 inches of sharp sand and 12 inches of fine gravel, after which it gathers in a large well, whence it is pumped to the reservoir.

ANALYSIS 8.—*Fulton city water.*[a]

	Parts per million.		Parts per million.
Residue on evaporation	520	Chlorine	11
Residue on ignition	435	Hardness	386
Free ammonia	.01	Color, clear.	
Albuminoid ammonia	.03	Odor, none.	
Nitrogen as nitrates	0	Reaction, alkaline.	
Nitrogen as nitrites	.96		

ANALYSIS 9.—*Higginsville city water, January 28, 1904.*[a]

	Parts per million.		Parts per million.
Silica (SiO_2)	18	Residue on evaporation	362
Iron (Fe)	2	Residue on ignition	338
Alumina (Al)	.15	Free ammonia	.03
Calcium (Ca)	51	Albuminoid ammonia	.2
Magnesium (Mg)	8	Nitrogen as nitrates	Trace.
Sulphate radicle (SO_4)	27	Nitrogen as nitrites	.004
Chlorine (Cl)	23	Oxygen consumed	2
		Color, clear.	
	129.15	Odor, none.	

[a] Bull. Missouri State Board of Health, vol. 1, No. 4, 1904; recomputed to ionic form at United States Geological Survey.

[b] Expressed by analyst in grains per gallon and hypothetical combinations; recomputed to ionic form and parts per million at United States Geological Survey.

[c] Sodium and potassium calculated as sodium.

ANALYSIS 10.—*Joplin city water.*

	Parts per million.		Parts per million.
Residue on evaporation	148	Iron	.02
Free ammonia	.005	Alkalinity	96
Albuminoid ammonia	.062	Permanent hardness	11
Nitrates	2.65	Free CO_2	1
Nitrites	.001	Bacteria per cubic centimeter, 5.	
Oxygen consumed	2	Bacillus coli communi, none.	
Chlorine	3.9		

ANALYSIS 11.—*Kirksville city water, April 4, 1904.* [a]

	Parts per million.		Parts per million.
Silica (SiO_2)	11	Residue on evaporation	188
Iron (Fe)	2.6	Residue on ignition	171
Alumina (Al)	.06	Free ammonia	.12
Calcium (Ca)	34	Albuminoid ammonia	.50
Magnesium (Mg)	8.1	Nitrogen as nitrates	.31
Sulphate radicle (SO_4)	35	Nitrogen as nitrites	0
Chlorine (Cl)	4.3	Oxygen consumed	7.6
	95.08	Color, clear.	
		Odor, none.	

ANALYSIS 12.—*Lebanon city water (artesian well, 1,000 feet).* [b]

	Parts per million.		Parts per million.
Silica (SiO_2)	11	Sulphate radicle (SO_4)	4.8
Iron (Fe)	Trace.	Chlorine (Cl)	Trace.
Aluminum (Al)	1.7	H, bicarbonate	3.4
Calcium (Ca)	33		285.9
Magnesium (Mg)	16	Free CO_2	70
Sodium (Na)	13		
Carbonate radicle (CO_3)	203		

A very fine water.

ANALYSIS 13.—*Marshall city water, January 27, 1904.* [c]

	Parts per million.		Parts per million.
Silica (SiO_2)	11	Residue on evaporation	1,202
Iron (Fe)	3.3	Residue on ignition	1,119
Aluminum (Al)	.9	Free ammonia	.342
Calcium (Ca)	156	Albuminoid ammonia	.13
Magnesium (Mg)	24	Nitrogen as nitrates	Trace.
Sulphate radicle (SO_4)	191	Nitrogen as nitrites	Trace.
Chlorine (Cl)	464	Oxygen consumed	1.95
	850.2	Color, very clear.	
		Odor, none.	

[a] Bull. Missouri State Board of Health, vol. 1, No. 4, 1904.

[b] Analysis by L. G. Eakins. Bull. U. S. Geol. Survey No. 60, p. 172.

[c] Analysis by Missouri State board of health. Recomputed to ionic form at United States Geological Survey.

ANALYSIS 14.—*Moberly city water (reservoir).* [a]

	Parts per million.	
Silica (SiO_2)	32	Odorless, tasteless.
Iron (Fe)	15	Slightly turbid, and of yellowish tint.
Calcium (Ca)	15	
Undetermined	21	
	83	

It contains the merest trace of chlorine and ammonia; no nitric acid; no albuminoid ammonia. The only life that could be determined was represented by specimens of cyclops and vesabia, appearing to the naked eye as moving specks.

ANALYSIS 15.—*Monett city water, March 2, 1904.* [b]

	Parts per million.		Parts per million.
Silica (SiO_2)	11	Residue on evaporation	237
Iron (Fe)	1.3	Residue on ignition	212
Aluminum (Al)	.05	Color, clear.	
Calcium (Ca)	.64	Odor, none.	
Magnesium (Mg)	7.5		
Sulphate radicle (SO_4)	50		
Chlorine (Cl)	8.2		
	142.05		

ANALYSIS 16.—*Nevada city water, April 4, 1904.* [c]

	Parts per million.		Parts per million.
Silica (SiO_2)	10	Residue on evaporation	1,319
Iron (Fe)	1.7	Residue on ignition	1,297
Aluminum (Al)	.1	Color, very clear.	
Calcium (Ca)	86	Odor, none.	
Magnesium (Mg)	39		
Sulphate radicle (SO_4)	86		
Chlorine (Cl)	576		
	798.8		

ANALYSIS 17.—*Oregon city water, May 25, 1899.* [c]

	Parts per million.		Parts per million.
Silica (SiO_2)	8.6	Carbonate radicle (CO_3)	235
Iron and alumina oxides (Fe_2O_3+ Al_2O_3)	16	Sulphate radicle (SO_4)	14
Calcium (Ca)	90	Chlorine (Cl)	16
Magnesium (Mg)	40		436.6
Sodium (Na)[d]	17		

[a] Analysis by Paul Schweitzer. Expressed by analyst in grains per gallon; recomputed to ionic form and parts per million at United States Geological Survey.

[b] Bull. Missouri State Board of Health, vol. 1, No. 4, 1904. Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

[c] Expressed by analyst in hypothetical combinations; recomputed to ionic form at United States Geological Survey.

[d] Sodium and potassium calculated as sodium.

ANALYSIS 18. *St. Joseph city water.*

	Parts per million.		Parts per million.
Albuminoid ammonia	0.55	Total solids	5970
Free ammonia	.04	Iron	5.1
Nitrogen as nitrates	.35	Alkalinity	104
Nitrogen as nitrites	0	Permanent hardness	60
Chlorine	11	Sulphuric acid	0
Oxygen consumed	25	Carbonic acid	8

Appearance, muddy; odor, none; color, 250 F. F. M.

ANALYSIS 19. *Slater city water, January 29, 1904.* [a]

	Parts per million.[a]		Parts per million.[a]
Silica (SiO_2)	5 2	Residue on evaporation	726
Iron (Fe)	1.7	Residue on ignition	598
Aluminum (Al)	.05		
Calcium (Ca)	83		
Magnesium (Mg)	29		
Sulphate radicle (SO_4)	67		
Chlorine (Cl)	166		
	351.95		

Color, very clear; odor, none.

ANALYSIS 20. *Springfield city water, May, 1905.* [b]

	Parts per million.		Parts per million
Silica (SiO_2)	9.4	Oxygen consumed	0.072
Iron (Fe)	1.4	Free ammonia	.1
Aluminum (Al)	.1	Albuminoid ammonia	.124
Calcium (Ca)	57	Nitrogen as nitrates	Trace.
Magnesium (Mg)	4.2	Nitrogen as nitrites	0
Sodium (Na)	2.6	Temporary hardness	165.7
Potassium (K)	Trace.	Permanent hardness	13.6
Bicarbonate radicle (HCO_3)	191	Total hardness	179.3
Sulphate radicle (SO_4)	5.8	Total dissolved solids	214.411
Chlorine (Cl)	3.9		
	275.4		

Color, very clear; odor, none.

ANALYSIS 21. *Tarkio city water.* [c]

DEEP WELL.

	Parts per million.		Parts per million
Chlorine	111	Temporary hardness	259
Free ammonia	8	Permanent hardness	367
Albuminoid ammonia	10	Total solids	1,442
Total hardness	626		

[a] Bull. Missouri State Board of Health, vol. 1, No. 4, 1904. Recomputed to ionic form at United States Geological Survey.

[b] Bull. Bradley Geol. Field Station, No. 11, Drury College. Chemical analysis by Miss Kate Lyman; sanitary analysis by Miss Etta Little. Recomputed to ionic form at United States Geological Survey.

[c] Analyses by Prof. J. C. Adair, of Tarkio College. See p. 191 for comments on the large amounts of albuminoid ammonia.

SURFACE WELL.

	Parts per million.		Parts per million.
Chlorine	1.6	Temporary hardness	142
Albuminoid ammonia	.06	Permanent hardness	40
Total hardness	182		

ANALYSIS 22. *Trenton city water, February 27, 1904.* [a]

	Parts per million.		Parts per million.
Silica (SiO_2)	5.5	Residue on evaporation	202
Iron (Fe)	8.6	Residue on ignition	175
Aluminum (Al)	1.4	Oxygen consumed	10.3
Calcium (Ca)	22	Free ammonia	.8
Magnesium (Mg)	5.3	Albuminoid ammonia	.6
Sulphate radicle (SO_4)	33	Nitrogen as nitrates	.32
Chlorine (Cl)	3.1	Nitrogen as nitrites	.0714
	78.9		

Odor, none.

ANALYSIS 23. *Warrensburg city water, February 6, 1904.* [a]

	Parts per million.		Parts per million.
Silica (SiO_2)	8.8	Residue on evaporation	168
Iron (Fe)	2.3	Oxygen consumed	3.4
Aluminum (Al)	.5	Free ammonia	.8
Calcium (Ca)	36	Albuminoid ammonia	.3
Magnesium (Mg)	8.5	Nitrogen as nitrates	.237
Sulphate radicle (SO_4)	35	Nitrogen as nitrites	0
Chlorine (Cl)	6.1		
	97.2		

Color, clear; odor, none.

ANALYSIS 24. *Webb city and Carterville city water, February 26, 1904.* [a]

	Parts per million.		Parts per million.
Silica (SiO_2)	76	Residue on evaporation	412
Iron (Fe)	2	Residue on ignition	381
Aluminum (Al)	.4	Oxygen consumed	1.15
Calcium (Ca)	95	Free ammonia	.096
Magnesium (Mg)	7.3	Albuminoid ammonia	.22
Sulphate radicle (SO_4)	202	Nitrogen as nitrates	1.56
Chlorine (Cl)	4.8	Nitrogen as nitrites	0
	387.5		

Color, clear; odor, none.

MINERAL WELLS.

The water of many wells is so highly charged with mineral salts as to be objectionable for general use, though in some of them it is extremely valuable from a medicinal standpoint. The wells at Excelsior Springs, Canton, Lagrange, St. Louis, and in other parts of the

[a] Bull. Missouri State Board of Health, vol. 1, No. 4, 1904. Recomputed to ionic form at United States Geological Survey.

State belong to this class. In regard to their value as therapeutic agents, Dr. Crook[a] makes the following statement:

There exists among medical practitioners in the United States a wide-spread skepticism regarding the medicinal value of mineral waters. This incredulity is, no doubt, based to a considerable extent upon a somewhat justifiable prejudice; but may it not be due, in a much greater degree, to a want of correct information? We are all acquainted with the mineral springs advertising circular. * * * When the intelligent practitioner reads that a certain water is positively curative in an imposing list of diseases set forth in divers pages of testimonials from renovated statesmen, restored clergymen, and rejuvenated old ladies, and then learns from the analysis that it contains 2 or 3 grains of lime salts to the gallon, with the remaining ingredients requiring perhaps a third or fourth decimal figure to express, he can hardly be blamed for tossing the circular into his waste-basket, with an objurgation upon quacks generally, and mineral-springs quacks in particular. Yet the conservative physician will find a safe and dignified position between that of the pretentious advertisement which claims everything and that of the medical skeptic who will believe nothing.

There is no doubt that much benefit is derived from most of the health resorts connected with mineral springs or wells; and while a great deal of it is undoubtedly psychic, some is unquestionably due to the use of the waters. People who are broken down from overwork or who are troubled with many incipient diseases find at these resorts rest, which they perhaps can not get elsewhere; a change of air; a new environment; possibly a change in climate or altitude; pleasant associations; distractions from trouble; and they use, both internally and externally, perhaps a much larger amount of water than has been their custom at home; these, together with faith in the curative properties of the water (since every wise physician recognizes faith as a useful element in cure), form a stimulus to nature in the restoration of normal action to the functions of the body.

The following constituents are more or less common in the concentrated residue of the waters of mineral wells and springs in Missouri. They are derived from the action of percolating waters in dissolving out many of the varied substances of the rocks through which they pass:

Silica.	Magnesium chloride.
Alumina.	Potassium bicarbonate.
Ferrous bicarbonate.	Potassium sulphate.
Ferrous sulphate.	Potassium chloride.
Manganous bicarbonate.	Potassium bromide.
Calcium bicarbonate.	Sodium carbonate.
Calcium sulphate.	Sodium chloride.
Calcium sulphydrate.	Sodium sulphate.
Calcium chloride.	Lithium chloride.
Calcium phosphate.	Oxygen.
Magnesium bicarbonate.	Carbon dioxide.
Magnesium sulphate.	Hydrogen sulphide.

[a] Mineral Waters of the United States, 1876, p. 54.

The therapeutic action of the individual elements is discussed by Hessler.[a]

Sodium chloride, or common salt, is found in all mineral waters in amounts varying from a mere trace up to several thousand grains per gallon. It is present in almost every tissue of the body, and a certain amount is required to keep the organs in a healthy condition. It "regulates absorption, nutrition, and secretion." Internally, "it may produce an increase of the gastric juice, bile, pancreatic juice, and intestinal fluids, promoting the appetite and assisting digestion."[b] It has a slight aperient effect on the bowels and probably tends to prevent intestinal decomposition. Its presence in water, in a nonsaline subsoil, is ordinarily an indication of sewage contamination as the only source from which it could be derived, since practically all of the salt taken into the animal body is passed out through the secretions.

Sodium sulphate, or Glauber salts, is a common and frequently abundant constituent, derived from the Pennsylvanian rocks and the Hannibal shales in Missouri. It is unessential in the healthy body. Hessler says:[c]

> Small doses stimulate the intestinal and urinary secretions, larger doses are laxative, and still larger doses are cathartic. * * * This salt is useful in some disordered conditions of the digestive tract—gastric, hepatic, and intestinal. * * * In certain dropsical conditions, as that dependent on some forms of heart disease, it may give relief by helping to abstract the accumulated fluid. * * * In a number of diseases the use of water containing much of this salt must be avoided.

Sodium sulphate occurs in considerable quantities in the B. B. mineral spring, the Lineville well, and the Allen well, at Versailles.

Sodium carbonate is found in the human body in the blood and saliva, both of which are alkaline in character. When taken into the system, these alkaline salts neutralize the free acids, and they are considered valuable in some cases of acid dyspepsia and the treatment of gallstones. According to Hessler[d]—

> The bicarbonate is usually prescribed. It is useful in certain affections marked by acid conditions, among which may be mentioned some of the fevers, rheumatism, gout, and irritable bladder, particularly if this irritation be due to the acidity of the urine, the latter becoming alkaline under its use. In uric-acid conditions the potassium bicarbonate is to be preferred.

The presence of sodium carbonate in water may sometimes aggravate certain diseases. The excessive use of soda will almost invariably derange the digestive system.

Potassium sulphate is a rare constituent of the mineral waters of Missouri. It somewhat resembles, in its action, sodium and magnesium sulphate.

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[a] Hessler, Robert, The medicinal properties and uses of Indiana mineral waters: Twenty-sixth and twenty-seventh Ann. Repts. Indiana Dept. Geology and Nat. Res., 1903, pp. 159, et seq.

[b] Hessler, Robert, op. cit., p. 167.

[c] Op. cit., pp. 167-168.

[d] Op. cit., p. 168.

Calcium carbonate is the most common of all the mineral constituents of waters of the State, being derived from the solution of the limestone in which it is found. It is "chiefly antacid and diuretic."

Calcium sulphate is a very common constituent of hard waters. It is usually present in small amounts, as it is not readily soluble. It has no especial action on the system.

Magnesium sulphate (Epsom salts) is characteristic of the waters from the Pennsylvanian rocks and the Hannibal shale. It is milder in its action and more agreeable to the taste than sodium sulphate or Glauber salts, and has a similar effect on the human system.

Magnesium carbonate is usually found in small quantities in the waters of the magnesium limestones (dolomites) that are so common through the central and southeastern parts of the State. It is an antacid.

Iron, usually the bicarbonate, is almost always present in water, either in minute traces or in small appreciable amounts. In the latter case it forms the important constituent of chalybeate springs and wells. The importance of iron as a tonic need not here be emphasized. "In many affections, notably in alterations of the blood, iron waters may be of decided benefit."[a]

Iron sulphate is sometimes found in the waters derived from the shales of the Pennsylvanian series. It is less palatable and more astringent than the bicarbonate, and when in excess is an objectionable constituent.

Aluminum sulphate is found but rarely, and in water derived from the Pennsylvanian shales. The water from the Versailles alum well, in Morgan County, contains 1,275 parts per million. It also occurs in one of the springs of the Graydon group, in Polk County. Alum is a very strong astringent, but has no other definite therapeutic character.

Carbonic acid gas is frequently found in mineral waters in small amounts. It has a soothing effect on the mucous membrane of the stomach and tends to allay nausea.

Hydrogen sulphide is a gas having the odor of rotten eggs and is a common constituent of the so-called sulphur waters. It is doubtful if this gas, especially when the amount usually ingested with the water is considered, has any influence on the body or is of any marked benefit in diseased conditions. Used externally, it may have some influence in certain skin diseases.

Warm sulphur baths may be useful in chronic lead poisoning, as that [illegible] Many of the famous sulphur waters are hot or thermal springs, and their virtues [illegible] from that of their accompanying constituents, are often due to the manner [illegible] they are used.[b]

[a] Hessler, Robert, op. cit., p. 171.

[b] Op. cit., p. 17[illegible].

BLOWING WELLS.

There is a blowing well in Camden County, near Decaturville, and one of greater interest on the farm of J. B. Murphy, near Raymondville, Texas County. This well, which is on a hill, was drilled in 1899 to a depth of 187 feet. Soft water was struck at the bottom and rose 7 feet in the well. In a dry time, especially in the winter, the well becomes dry. In drilling it, a cave 3 feet high was struck at a depth of 100 feet. When the well is dry, if there is a long prevailing wind from the north, a current of air rushes from the pipe strong enough to blow the cap from the tubing. This fact illustrates the honeycombed and cavernous nature of the rocks in this region. About 10 miles to the north, in the valley of Ashley Creek, is what Schoolcraft described in the account of his trip through this region in 1818 as "the valley of caves." Here in the eroded bluffs may be seen numerous caves which testify to the great amount of underground drainage, and through which probably the prevailing winds are sucked underground and carried for long distances.

The traveler passing south from the crest of the Ozark plateau, crosses a belt throughout which sink holes prevail, a fact noticed by Schoolcraft, who refers to the locality as "the prairie of little lakes." The large amount of water that soaks into the catchment basin of the Ozark dome quickly begins its work of solution by forming underground cavernous waterways, manifested at the surface in numerous places by sink holes, many of which form ponds. The gradual evolution of valleys by the cutting out of strata and the merging of these sink holes into continuous gorges can not be fully discussed here, but it is a most interesting phase of underground drainage. In some cases a section of the barrier between two sink holes resists erosion and an arch is left which forms a natural bridge. A beautiful illustration of this kind of erosion is found on Sinking Creek, Shannon County, where the large stream runs through a tortuous gorge formed by the undermining and washing out of a chain of sink holes. In one part of its course it meets a barrier of which only the lower portion is removed, and thus is formed the unusual natural feature of a stream running under a mountain and continuing its course through an eroded gorge on the other side. The channel of this stream is 40 feet deep, and one may easily ride in a boat through its course under the mountain. The accompanying illustration (Pl. VI, *B*, p. 80) shows this underground channel.

Where normal valleys cut at right angles across the line of drainage, as in "the valley of caves," there may be had a glimpse of a cross section showing the vast amount of underdrainage along the south slopes of the Ozarks. Farther south, in Shannon and adjoining counties, are

some of the outlets of this deeper system of underground drainage, manifested in springs which are probably the largest in the world. The enormous deeper seated drainage passes underneath the embayment area and helps to form the artesian basin.

The numerous cases of cold-air drafts from caves, springs, and drill wells are easily explained when the geologic structure of the region is studied.

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WS 142. Hydrology of San Bernardino Valley, California, by W. C. Mendenhall. 1905. 124 pp., 13 pls.

WS 145. Contributions to the hydrology of eastern United States; M. L. Fuller, geologist in charge. 1905. 220 pp., 6 pls.

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PP 52. Geology and underground waters of the Arkansas Valley in eastern Colorado, by N. H. Darton. 1906. 90 pp., 28 pls.

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WS 183. Flowing wells and municipal water supplies in the middle and northern portions of the Southern Peninsula of Michigan, by Frank Leverett and others. 1906. 398 pp., 5 pls.

B 298. Record of deep-well drilling for 1905, by M. L. Fuller and Samuel Sanford. 1906. 299 pp.

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WS 188. Water resources of the Rio Grande Valley in New Mexico and their development, by W. T. Lee. 1906. 59 pp., 10 pls.

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WS 191. Geology and water resources of the western portion of the Panhandle of Texas, by C. N. Gould. 1907. 70 pp., 7 pls.

WS 195. Underground waters of Missouri; their geology and utilization, by Edward Shepard. 1907. 224 pp., 6 pls.

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

WATER SUPPLY

OF

: REGION, SEWARD PENINSULA, ALASKA

1906

BY

JOHN C. HOYT AND FRED F. HENSHAW

WASHINGTON
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WATER SUPPLY OF NOME REGION, SEWARD PENINSULA, ALASKA, 1906.

By John C. Hoyt and Fred F. Henshaw.

INTRODUCTION.

The successful operation of a placer deposit depends primarily upon the water supply. Data in regard to this supply are essential to its economical development, and lack of such information in regard to the flow of streams has often caused financial failure in mining as well as in other enterprises which depend on water.

For a number of years the United States Geological Survey has made in the United States systematic measurements and studies of the water supply as one of the great resources of the country. These data are now available for all of the more important streams, and are extensively used by engineers and others in problems involving water power, city water supply, irrigation, and manufacturing.

During the season of 1906 the Survey extended these investigations to Alaska in order that information in regard to water supply may be available for the economical development of the placer mines and water power of that territory. The field work was carried on from June 11 to October 3. The work necessary for the preparation of this report was done under the direction of the water-resources branch, but the expenses were paid from the appropriation for the investigation of the mineral resources of Alaska.

The limited funds available made it necessary to restrict the investigations to a comparatively limited area. Owing to the rich placers and extensive mining in the vicinity of Nome the work was confined to streams of that section, special attention being given to the more important of those that supply water for working the rich deposits back of Nome. The gaging stations were so located (see Pl. I and the following list) that the measurements should show the water available in this important area. The additional supply below the points of measurement may in many cases have a local value, as has also the water of many of the smaller streams, but it was impossible to measure them on account of the limited funds. The data obtained, however, give a fair idea of the conditions of flow that may be expected at points in the vicinity where measurements were made (see pp. 44–47) and are also of value in determining the flow that may be expected in other parts of this region.

List of gaging stations.[a]

1. Nome River above Miocene intake.
2. Buffalo Creek.
3. Dorothy Creek.
4. Miocene ditch at Black Point.
5. Miocene ditch at flume.
6. Hobson Creek at Miocene ditch crossing.
7. David Creek ditch intake.
8. Seward ditch intake.
9. Grand Central River (north fork) at elevation 750 feet.
10. Grand Central River (north fork) at elevation 1,030 feet.
11. Grand Central River (west fork) at elevation 860 feet.
12. Grand Central River (west fork) at elevation 1,010 feet.
13. Crater Lake outlet.
14. Grand Central River below forks.
15. Grand Central River below Nugget Creek.
16. Gold Run.
17. Thompson Creek.
18. Nugget Creek.
19. Copper Creek.
20. Jett Creek.
21. Morning Call Creek.
22. Kruzgamepa River at outlet of Salmon Lake.
23. Crater Creek.
24. Iron Creek below mouth of Canyon Creek.
25. Iron (Dome) Creek.
26. Eldorado Creek.
27. Discovery Creek.
28. Canyon Creek.
29. Sinuk River.
30. Windy Creek.
31. North Star Creek.
32. Stewart River.
33. Slate Creek.
34. Josie Creek.
35. Irene Creek.
36. Jessie Creek.
37. Upper Oregon Creek.
38. Slate Creek.
39. Aurora Creek.
40. Penny River at elevation 420 feet.
41. Penny River at elevation 120 feet.
42. Eldorado River.
43. Fall Creek.
44. Glacier Creek.
45. Snow Gulch.

The hearty cooperation of the mining and other interests in th vicinity of Nome greatly facilitated the work. In this connectio special acknowledgment is made to the officers and employees of th Miocene Ditch Company, Wild Goose Mining and Trading Compan

[a] Number refers to Pl. I.

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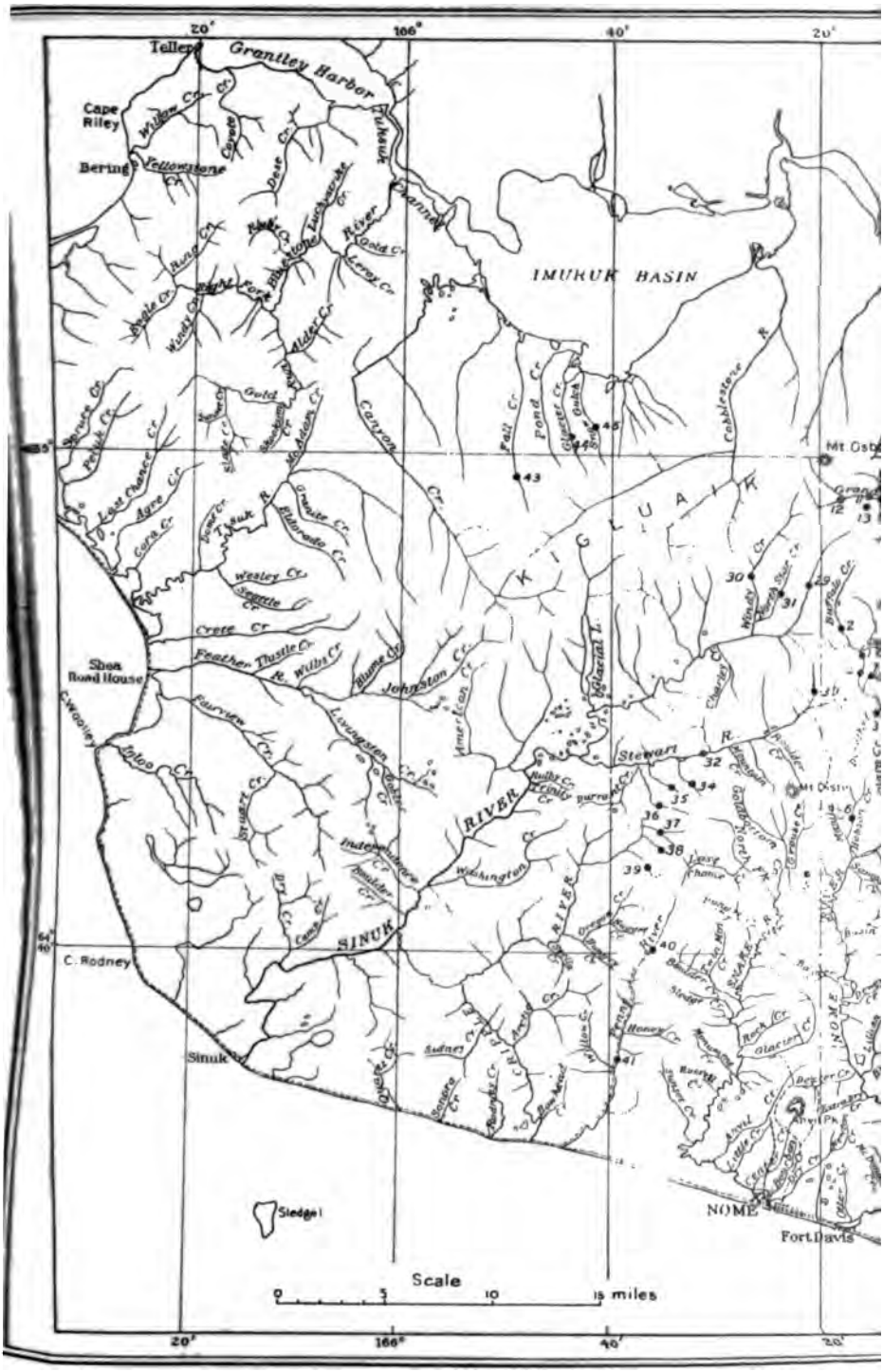


MAP SHOWING LOCATION

Cedric Ditch Company, Pioneer Mining Company, Gold Beach Development Company, and the United Ditch Company; to W. L. Leland, of the Three Friends Mining Company; to J. E. Styers, superintendent of the National Wood Pipe Company; and to Arthur Gibson, George Ashley, William E. Morris, J. Potter Whittren, and George M. Ashford, civil and mining engineers, Nome.

GENERAL DESCRIPTION OF AREA.

The region covered by this investigation is, in a general way, 15 to 20 miles wide and stretches 40 miles inland from the town of Nome, which is situated on the southern coast of the Seward Peninsula. While most of the measurements were made about 20 to 25 miles from the coast, at points where the altitude is sufficiently high to make the water available for mining high-level placers, some trips were also made into the adjacent regions to the east and west.

The region embraces three types of topography, which, from south to north, are (1) a coastal plain, (2) an upland, and (3) a mountain mass.

Bordering the coast line between Cape Nome and Cape Rodney is an area of low relief, which stretches back to the foothills with a width of from 2 to 5 miles. This lowland, known as the Nome tundra, is made up in general of wet moss-covered ground, rising with a gentle slope to an elevation of between 200 and 300 feet at the southern margin of the upland.

The ridges that constitute the upland trend in a general way north and south, rising from about 700 feet near the coast to 2,000 feet 30 miles inland. These ridges are separated by the broad U-shaped valleys of the larger drainage courses. Thirty miles from the coast the ridges are united by an east-west ridge, which presents a steep escarpment toward a broad depression to the north. This depression separates the upland from the Kigluaik Mountains.

The east-west ridge is broken by broad low gaps, a feature of great importance to the engineer who contemplates tapping the water resources of the Kigluaik Mountains. North of the depression the Kigluaik Mountains, locally known as the Sawtooth Range, rise abruptly, constituting a rugged east-west mass, sharply dissected, with serrated crest line. As these mountains have been the center of local glaciation in recent times, their valleys are characterized by cirques, which form important sources of water for the district.

Most of the area here considered drains southward to Bering Sea through Nome and Snake rivers, whose sources lie close to the ridge which forms the northern boundary of the upland. Besides these, a part of the waters of the upland also flow southward to Bering Sea through Eldorado, Flambeau, Cripple, and Penny rivers. The valleys of all of these are of about the same type—broad and deep in the

upland, with gentle slopes for 300 to 600 feet, then steeper walled to crest lines, which vary from 800 to 1,500 feet in altitude. Their floors are usually covered with gravels. Some of the smaller tributaries occupy sharply incised trenches and have but a thin coating of gravel on their rock floors.

The east and west depression which separates the upland from the mountains to the north is drained in part by streams flowing west to Sinuk River, which empties into Bering Sea, and in part by streams flowing east to Kruzgamepa River, which discharges into Imuruk Basin. The streams draining the southern slope of the Kigluaik Mountains are all tributary to one or the other of the two systems. Many of them head in glacial cirques and flow through steep-walled rock-bound valleys, and all have torrential courses.

The general character of all the drainage areas is the same (see Pl. II). The streams have little slope, except in their extreme upper portions, and spread over wide gravelly beds, in which they often divide into several channels or disappear in the gravel. The channels are also subject to considerable shifting during floods. For from 1,000 to 3,000 feet on either side of this gravelly bed extend level or gentle-sloping bottom lands, from which the hills rise quite abruptly. The drainage basins are from 4 to 12 miles wide. The tributary streams are in most cases short and flow in narrow ravines having steep sides. Their slope is great, and in many cases they are made up of a series of rapids, waterfalls, and pools.

Practically the whole country to an elevation of 1,000 feet is covered with a thick turf, commonly known as "tundra" (see Pl. III, A). On this in the summer there is a rank growth of grass dotted with wild flowers of many varieties, and in some areas there is considerable moss. There are no trees with the exception of occasional patches of scrub willow and alder, which in the absence of better fuel can be used for firewood. Much of the ground within 2 feet of the surface remains frozen throughout the year. The soil in the lowlands is mostly gravel overlain with muck, and often contains a large per cent of water which, when it thaws out in the summer time, makes the muck very soft. Some considerable areas are underlain by clear ice. The hills are composed largely of schist and limestone rock, mantled with loose slide and gravel. Thawing often causes serious slides.

CONDITIONS AFFECTING WATER SUPPLY.

Three sources of water supply contribute to the run-off of the Seward Peninsula: (1) Summer rains; (2) melting of accumulated snow; (3) ground water originating mostly from melting ice.

Of the rainfall there is but little direct data, as few rainfall records were kept in this section until the present year, when four rainfall stations were established in connection with the hydrographic studies

TYPICAL TOPOGRAPHY OF SEWARD PENINSULA.

The present year was one of drought; therefore the records can not be taken as a mean.

The four rain gages were located at Nome, at Salmon Lake, at Claim No. 15 Ophir Creek, and at Deering. The gage at Nome was read by Mr. Arthur Gibson. It was located on the roof of a house, about 20 feet above the ground and about 40 feet above sea level. The gage at Salmon Lake was placed on the ground at an elevation of about 450 feet above sea level and was read by Mr. John P. Samuelson. The location of the gage at No. 15 Ophir is not known. No records were obtained from Deering.

During the month of June there was only a trace of rain on one day at Nome, and on three days at Salmon Lake. During the present season it was also noted that the country is subject to local showers.

The only previous record known to have been kept at Nome was made in 1900, when the precipitation was 0.60 of an inch from August 13 to 31 and 7 inches in September.

The following data, compiled from observations by members of the Geological Survey and from other sources, throw some light on the general weather conditions of Seward Peninsula for the last eight years:

1899. July, 4 rainy days; August, 14 rainy days; September, 14 rainy days; recorded at Teller.

1900. June to July, inclusive, warm and dry, tundra fires common; August to end of September, rain.

1901. June to August, inclusive, cold and foggy with some rain; September to October, inclusive, usually clear and cold with one or two hard rains of few days' duration.

1902. June, dry; July, 10 rainy days; August, 6 rainy days; September, 3 rainy days; recorded at Teller.

1903. Summer warm; little rain, but considerable fog.

1904. June, dry; rainy days as follows: 10 in July, 10 in August, 10 in September; temperature moderate.

1905. Very wet and cold the whole season.

1906. Very warm and dry; tundra fires common; temperature reached as high as 85°.

The following tables give the mean monthly and the daily precipitation at the various stations during 1906:

Monthly rainfall, in inches, in Nome region, June to September, 1906.

Station.	June.	July.	August.	September.	Total, June to August.	Total, June to September.
Nome	Trace.	2.38	2.50	1.02	4.88	5.90
Salmon Lake	Trace.	4.92	3.33	3.26	8.25	11.51
Ophir	Trace.	3.57	1.91	(a)	5.48	.....

a No record.

Daily rainfall, in inches, at stations near Nome, 1906.

	July.			August.			Septem
	Nome.	Salmon Lake.	Ophir.	Nome.	Salmon Lake.	Ophir.	Nome.
1							
2						Trace.	0.01
3		0.12					
4		.35			0.17	0.01	
5		.35		0.07	.07	.05	
6		.10	0.02		.23	.03	
7	a 0.52	.17	.23	b .41	.28		
8	.37	2.32	1.30				
9	.92	.31	.19	Trace.	.29	.08	
10	.14	.25				.12	
11			.85			.01	
12	.04		.01		.10		
13			.02				.12
14		.35	.01				.40
15			.02				
16			.02				
17					.10		.14
18			.01				.9
19						.21	.2
20					.57	.31	.2
21		.25	.01	.80			.6
22			.01				
23	.08		.60	.22	.50	.22	
24	.27	.35	.25				
25	.04		.01	.04	.01	.05	
26				.37	.78	.40	
27			.01	.30	.23	.32	
28				.14			
29				.15			
30							
31							
Total	2.38	4.92	3.57	2.50	3.33	1.91	1.92

a Total, July 1–7. b Total, Aug. 6–7.

NOTE.—During June there was no measurable precipitation at any of the stations.

No data as to actual quantity of snowfall are available, bu conversation with residents it is believed that the annual snow not great, seldom exceeding from 2 to 3 feet. With the ex of the drifts which form in the gulches and the ice banks al beds of the rivers practically all snow in the drainage studied before the first of June; therefore, excepting the streams sources are in the protected gulches, the snow storage has b effect upon the run-off.

The ground water comes from the melting of the frozen which carries a large per cent of water. Its quantity depend fore, on the temperature and surface covering and action The thawing of the ground is slow and never reaches any grea so the rain does not have an opportunity to be taken up as storage, except late in the season. Early frosts, however, i with this storage, so that it can be said that practically all the water comes from melting ice.

With the exception of Sinuk and Nome rivers, which ha sources in the Kigluaik, a short distance apart, the streams into Bering Sea rise in the low foothills south of the Kigluaik Their drainage areas have a direct southern exposure and pra

A. TUNDRA BETWEEN BEACH AND FOOTHILLS.

B. MIOCENE DITCH, GLACIER CREEK.

all the snow on them is melted by the first of June. They are therefore limited for their water supply to the summer rains and the ground water from the melting ground.

The gulches in the Kigluaik are more protected and hold their snow much later in the season. There are also occasional summer snows in these mountains, so that the streams which rise in them have a much better sustained flow.

Owing to the steep slopes, lack of other vegetation than grass, and nearness of the frozen ground to the surface, the water from rainfall and thawing finds its way into the streams in a very short time. Flood flow comes immediately after showers and extreme warm

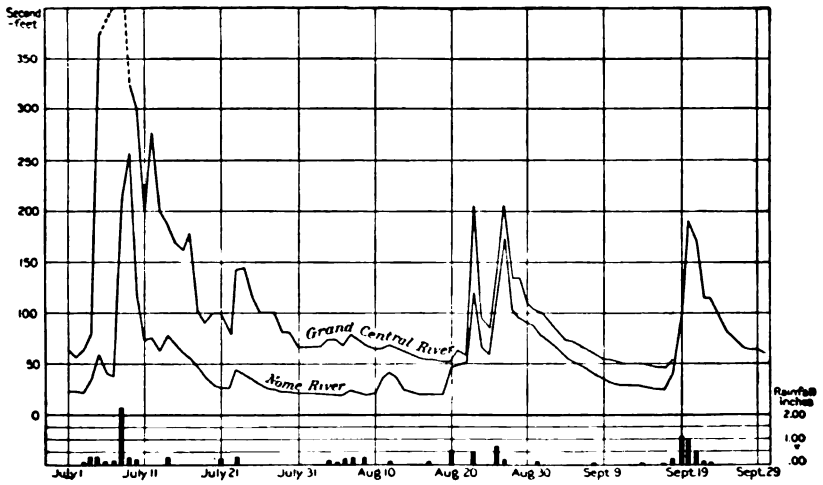


FIG. 1—Diagram showing flow of Nome River above Miocene intake and of Grand Central River below the forks.

spells and is usually of short duration, as there is no way in which the excess water can be taken up by the ground and stored (see fig. 1). In going along the Miocene ditch during the heavy storm of July 8, 1906, it was noted that although all supply gates were closed and the waste gates were open, the ditch was running full from the rain water coming in from the drainage above. Owing to this lack of ground storage, which is one of the important factors of maintaining a well-sustained stream flow in warmer climates, the streams depend on the rainfall and melting ice and respond very quickly to an increase in either of these two factors. Therefore, when the rainfall is slight, as in the past year and in 1900, the stream flow will be small.

MEASUREMENTS OF FLOW.

EXPLANATION OF DATA AND METHODS OF WORK.

The methods of carrying on the work and collecting the data were substantially the same as those previously used for similar work and

described in Water-Supply Papers Nos. 94, 95, and 167. They may be briefly outlined as follows:

In the consideration of industrial or mining enterprises which use the water of streams, it is essential to know the total amount of the water flowing in the stream, the daily distribution of the flow, and facts in regard to the conditions affecting the flow. Several terms are used, such as second-foot, miner's inch, gallons per minute, etc., to describe the quantity of water flowing in a stream, the one selected depending on the use to be made of the data.

"Second-foot" is in most general use for all classes of work, and from it the quantity expressed in other terms may be obtained.[a] It is an abbreviation of cubic foot per second and may be defined as the quantity of water flowing in a stream 1 foot wide and 1 foot deep at the rate of 1 foot per second. It should be noted that it is a rate of flow, and to obtain the actual quantity of water it is necessary to multiply it by the time.

"Second-feet per square mile" is the average number of cubic feet of water flowing per second from each square mile of area drained, on the assumption that the run-off is distributed uniformly, as regards both time and area.

"Run-off in inches" is the depth to which the drainage area would be covered if all the water flowing from it in a given period were conserved and uniformly distributed on the surface. It is used for comparing run-off with rainfall, which is expressed in depth in inches.

"Acre-foot" is equivalent to 43,560 cubic feet, and is the quantity required to cover an acre to the depth of 1 foot. It is commonly used in connection with storage problems.

The "miner's inch," the unit used in connection with placer mining, also expresses a rate of flow, and is the quantity of water flowing through an orifice of a given size, with a given head. The head and size of the orifice used in different localities vary, thus making it a most indefinite and unsatisfactory unit. Owing to the confusion arising from its use, it has been defined by law in several States. The California miner's inch is in most common use and was defined by an act approved March 23, 1901, as follows: "The standard miner's inch of water shall be equivalent or equal to 1½ cubic feet of water per minute, measured through any aperture or orifice."

The determination of the quantity of water flowing past a certain section of a stream at a given time is called a "discharge measurement," and points where regular measurements are made are called "gaging stations." Hydrographic field work consists in measuring

[a] The miner's inch is generally regarded as one-fortieth or one-fiftieth of a second-foot; therefore, to reduce second-feet to miner's inches it is necessary to multiply by either 40 or 50.

the area of the cross section of a stream and the velocity of its current. The product of these two factors gives the discharge.

In making a measurement a tapeline is stretched across the stream (see Pl. IV, *B*), and depth and velocity are measured at regular intervals (varying from 1 to 5 feet apart, depending on the size of the stream). The depths from which the area of the cross section is computed are taken by sounding with a graduated rod. The velocities are measured by a current meter (see Pl. IV, *A*). As the velocity varies with the depth, observations are taken near the surface, at middepth, and near the bottom. The mean of the velocities at these points gives the mean velocity for that vertical section.

One of the general laws of the flow of streams with permanent cross sections is that the discharge varies directly with the stage, or gage height, and that it will be the same whenever the stage or gage height of the stream is the same. Therefore, in order to determine the daily discharge of a stream, a gage on which the fluctuations of the surface of the stream may be noted is installed and read daily. As the discharge regularly increases with the stage, it is possible with a few discharge measurements taken at various stages to construct a rating curve which will give the discharge at all stages. The beds of most of the streams measured changed but little during the season and it was therefore possible to obtain the daily flow as just stated.

Water to be of use for mining purposes must be available under considerable pressure, or when diversion is necessary it must be taken at an elevation high enough to allow it to be carried over the divides. The gaging stations, therefore, were so established as to obtain measurements at points whose elevations were sufficient to permit the stream to be diverted for use in mining on the ground already prospected. Such stations were established on all the important streams in the area. At some of the locations it was impossible to secure gage readers to take the daily observations of river height, and for these stations it is only possible, therefore, to give the flow at the time of the actual discharge measurements. The following pages give the results of measurements on the various streams:

NOME RIVER DRAINAGE BASIN.

GENERAL DESCRIPTION.

Nome River is formed by the junction of Buffalo and Deep Canyon creeks, which have their sources in the Kigluaik Range. It has a drainage area of 150 square miles and flows in a general southerly direction through a valley having a length of about 40 miles and a width varying from 4 to 6 miles. The elevation at the headwaters

is between 3,000 and 4,000 feet, while the altitude of the ridges that bound the valley on the east and west averages 1,000 feet. The principal tributaries are David, Sulphur, Darling, Buster, and Osborn creeks from the east and Divide, Dorothy, Clara, and Hobson creeks from the west.

Nome River is the most important source of water for use in hydraulicking the rich placer deposits on the old beach lines back of Nome. Four ditches have been built to divert water for mining purposes. These systems, with the elevations of their intakes, are the Campion, 610 feet; Miocene, 572 feet; Seward, 407 feet; and Pioneer, 340 feet.

Any additional water supply that may be obtained in other high-level streams can best be brought to the mines by way of the valley of Nome River. During the season of 1906 the waters of Nugget, Copper, and Jett creeks were diverted over the Nugget divide by branches of the Miocene system.

Discharge measurements made in this drainage are given in the following pages:

NOME RIVER ABOVE MIOCENE INTAKE.

This station, elevation about 575 feet, is located between the junction of Buffalo and Deep Canyon creeks and the intake of Miocene ditch. At low water the river at this point has a width of about 30 feet, a depth of 1½ feet, and a mean velocity of 1 foot per second. The gage was read twice daily by employees of the Miocene Ditch Company.

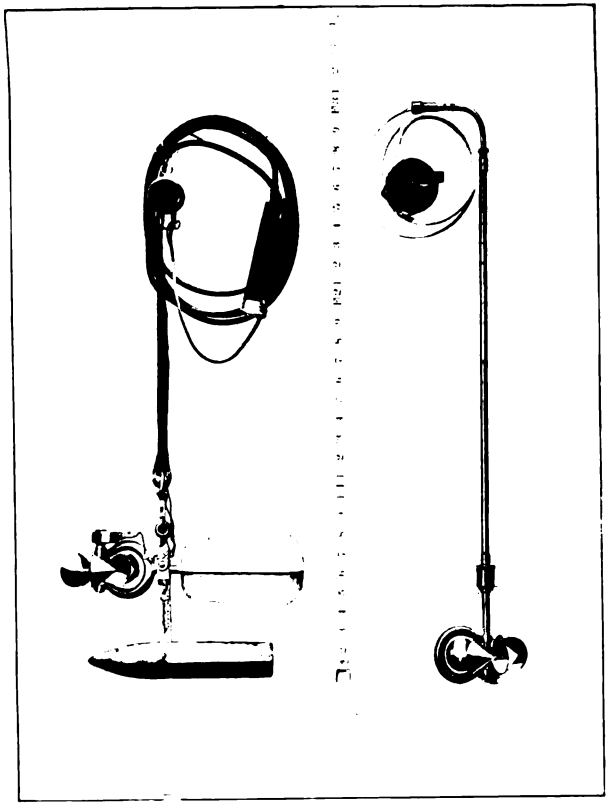
The flow at this station is affected by four ditches: Campion ditch, which diverts water from above the station, and Jett Creek, David Creek, and Grand Central ditches, which bring in water above the station from outside the area. In order to obtain the natural flow of the river, the mean flow of Campion ditch has been added to the flow at the gaging station and the flow of the other three ditches subtracted.

Discharge measurements of Nome River above Miocene intake in 1906.

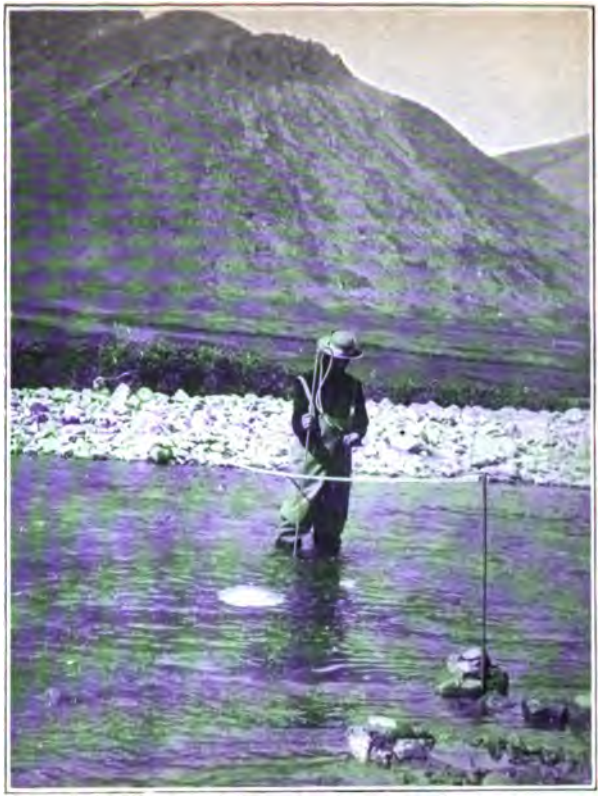
[Elevation, 575 feet.]

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec.-ft.*		*Feet.*	*Sec.-ft.*
June 17 [a]		39	July 14	.82	117
June 28	0.15	28	August 3	−.01	21.4
July 3	.00	21	August 23	.87	121
July 5	.45	54.7	August 23	.70	87
July 14	.40	50.5			

[a] One-half mile above Dorothy Creek.



A. PRICE CURRENT METERS.



B. MEASURING GRAND CENTRAL RIVER.

Mean daily gage height and discharge of Nome River at Miocene intake, 1906.

[Drainage area, 15 square miles.]

Day.	July.		August.		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1	.....	23	0.02	22	0.61	78
2	.....	23	.0	21	.57	72
3	0.00	21	−.01	21	.52	65
4	.25	35	−.02	20	.46	57
5	.48	59	−.04	20	.42	52
6	.31	40	−.04	20	.40	49
7	.28	37	+.09	25	.36	45
8	1.31	214	+.04	23	.36	39
9	1.5	260	−.02	20	.27	37
10	.85	119	.0	21	.21	32
11	.58	73	+.26	36	.18	30
12	.6	76	.34	43	.18	30
13	.5	62	.28	37	.18	30
14	.61	78	.10	25	.15	28
15	.56	70	.04	23	.12	26
16	.49	61	.03	22	.10	25
17	.45	56	.02	22	.10	25
18	.38	47	.0	21	.32	41
19	.26	36	.0	21	.70	92
20	.16	29	+.38	47	1.22	194
21	.14	27	.41	50	1.12	172
22	.13	27	.42	52	.83	115
23	.36	45	.87	123	.82	114
24	.31	40	.53	66	.74	99
25	.26	36	.48	59	.65	84
26	.18	30	.80	110	.6	76
27	.12	26	1.14	176	.54	68
28	.09	25	.78	106	.52	65
29	.06	23	.72	96	.52	65
30	.04	23	.70	92	.5	62
31	.02	22	.62	79	.....	.....
Mean at gaging station	.....	56.2	.....	49.0	.....	65.6
Mean of Campion ditch	.....	5.2	.....	14.4	.....	15.8
Total	.....	61.4	.....	63.4	.....	81.4
David Creek ditch	.....	[a] 6	.....	6	.....	[a] 7
Jett Creek ditch	.....	[a] 1	.....	[a] 3	.....	[a] 5
Grand Central ditch (Nugget Creek)	.....	[a] 3	.....	[a] 4	.....	[a] 5
Total	.....	10	.....	13	.....	17
Natural flow of Nome River	.....	51.4	.....	50.4	.....	64.4
Run-off per square mile	.....	3.43	.....	3.36	.....	4.29
Run-off, depth in inches	.....	3.95	.....	3.87		4.79

[a] Approximate.

BUFFALO CREEK.

Buffalo Creek rises in a deep canyon on the south side of the Kigluaik Mountains. From this canyon it joins Deep Canyon Creek and forms Nome River. Measurements were made as follows:

Discharge measurements on Buffalo Creek in 1906.

[Elevation, 800 feet; drainage area, 4.4 square miles.]

Date.	Discharge.
	Sec.-feet.
June 28	18.1
July 6	23.3
August 3	9.1

DOROTHY CREEK.

Dorothy Creek, which enters Nome River from the southwest, is a short, precipitous stream. It receives water from Campion ditch, as noted on page 21. The following discharge measurements were made above the outlet of the ditch:

Discharge measurements on Dorothy Creek in 1906.

[Elevation, 500 feet; drainage area, 2.7 square miles.]

Date.	Discharge.
	Sec.-feet.
June 16	5.1
July 29	3.0
August 18	2.9

THE MIOCENE DITCH SYSTEM.

GENERAL DESCRIPTION.

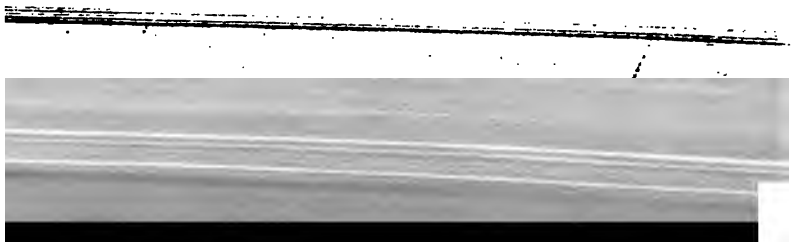
The Miocene ditch system includes 31 miles of main ditch and 31 miles of lateral feeders and distributing ditches, 8 miles of which are under construction (see Pl. III, *B*, and Pl. V). This ditch diverts water from upper Glacier Creek, upper Snake River, Nome River and its tributaries, and from the Grand Central River drainage for use on claims along lower Glacier, Dexter, and Anvil creeks.

The first section of this system was built in 1901, from upper Glacier Creek to Snow Gulch, this being the first ditch in Seward Peninsula. In 1902 an extension was made from Ex to Hobson Creek, and in 1903 it was extended to the head of Nome River, these three sections constituting the main line of the system, with a length of 31 miles. The elevation of the intake is 572 feet and that of the lower end 420, giving a fall of 152 feet. This fall varies along the ditch from 3.37 to 7 feet per mile. There are two siphons, one at Dorothy Creek, 24 inches by 300 feet, which carries about 40 second-feet, and one at Manila Creek, 40 inches by 1,000 feet. Below Willow Creek there is a 1,100-foot flume. The main ditch has an average width of 8 feet above and 10 feet below Hobson and a capacity of 60 second-feet. The mean flow is about 40 second-feet.

The water is delivered from the end of the ditch on claims along Glacier Creek; on Anvil Creek by a tunnel 1,800 feet long and 4 by 6 feet in cross section, built in 1903 and 1904; and on Dexter Creek by a ditch from Ex around the south side of King Mountain.

The lateral feeders, in order up the ditch, are: (1) From upper Glacier to Ex (this was the upper portion of the first section of the main ditch); (2) Grouse and Cold creeks to flume; (3) Upper New Eldorado to Sparkle Creek (this section is to be connected to the main ditch by a siphon across Nome River); (4) David Creek ditch, which empties into Nome River above the intake; (5) Jett Creek ditch, which runs along the south side of the Nugget divide into Deep Canyon and takes water from Jett and Copper creeks; (6) Grand Central

ROCK CUT AROUND CAPE HORN ON MIOCENE DITCH.



h is under construction (this ditch diverts water from ek and will tap the headwaters of Grand Central River). water can not be turned into ditches in this region before ere is too much frost in the ground. In 1906 the water of ek was turned into the ditch about June 20 and of Nome t June 26, but before July 1 was turned out frequently to pairs. The ditch was also out of use on account of a break 8 to 11, inclusive, after which date the water ran almost

wing pages give the results of measurements on ditches em.

MIOCENE DITCH AT BLACK POINT.

nents of flow were made at this point, about 1 mile below to determine the amount of water diverted from Nome e Miocene ditch. The gage was read by employees of the tch Company.

scharge measurements of Miocene ditch at Black Point in 1906.

e.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec.-ft.*		*Feet.*	*Sec.-ft.*
.....	0.80	31.8	August 2	0.39	18.1
.....	.89	34.1	August 11	1.20	44.7
.....	.71	27.5	August 23	1.30	48.3
.....	.68	25.7	September 11	.85	30.7
.....	.46	20.6	September 25	1.10	38.2

aily gage height and discharge of Miocene ditch at Black Point, 1906.

Day.	July.		August		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
.....	0.7	27	0.4	18.8	1.2	43.5
.....	.7	27	.38	18.5	1.2	43.5
.....	.6	24	.35	18	1.2	43.5
.....	.85	31.5	.34	17.8	1.2	43.5
.....	.95	34.8	.33	17.7	1.2	43.5
.....	.88	32.4	.34	17.8	1.2	43.5
.....	.85	31.5	.52	21.6	1.17	42.4
.....	.....	0*	.48	20.6	1.04	37.9
.....	.....	0	.37	18.3	1.0	36.5
.....	.....	0	.40	18.8	.98	35.8
.....	.5	21	.81	30.3	.82	30.6
.....	1.0	36.5	.82	30.6	.8	30
.....	1.0	36.5	.96	35.1	.8	30
.....	1.0	36.5	.6	24	.76	28.8
.....	1.2	43.5	.5	21	.72	27.6
.....	1.1	40	.5	21	.66	25.8
.....	1.1	40	.45	19.9	.64	25.2
.....	1.1	40	.39	18.6	.78	29.4
.....	.92	33.7	.46	20.1	.80	30
.....	.7	27	.86	31.8	.58	23.4
.....	.7	27	1.12	40.7	.69	26.7
.....	.62	24.6	1.03	37.6	.92	33.7
.....	.85	31.5	1.17	42.4	1.0	36.5
.....	.95	34.8	1.19	43.2	.96	35.1
.....	.92	33.7	1.2	43.5	1.05	38.2
.....	.75	28.5	1.17	42.4	1.06	38.6
.....	.62	24.6	1.16	42.1	1.22	44.2
.....	.54	22.2	1.2	43.5	1.2	43.5
.....	.5	21	1.2	43.5	1.2	43.5
.....	.45	19.9	1.2	43.5	1.2	43.5
.....	.42	19.2	1.2	43.5	.....	.....
.....	.....	27.4	.....	29.2	.....	35.9

MIOCENE DITCH AT THE FLUME.

This station was established to determine the amount of wate entering the ditch between the intake at Black Point and the flum This water includes seepage from the bank and the flow of sever small creeks—10 to 15 second-feet at low water from Hobson Cree and a small amount from the branch ditch to Grouse Creek. Th flume has a grade of 7 feet to the mile, a width of 8 feet, and a heig of 28 inches. On September 25 a measurement was made to dete mine its capacity with the water 2 feet deep, when the flow proved t be nearly 60 second-feet. This exceeds the safe capacity of the dit in the vicinity of the flume. The gage was read by employees of th Miocene Ditch Company.

Discharge measurements of Miocene ditch at flume in 1906.

Date.	Gage height.	Discharge.	Date.	Gage height.	Dis-charge
	Feet.	*Sec.-ft.*		*Feet.*	*Sec.-f*
July 4	0.95	29.8	September 11	1.50	[illegible]
July 27	1.08	36.5	September 25	1.85	[illegible]
August 2	.81	28.3	September 26	1.65	[illegible]

Mean daily gage height and discharge of Miocene ditch at flume, 1906.

Day.	July.		August.		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Dis-charge
	Ft.	*Sec.-ft.*	*Ft.*	*Sec.-ft.*	*Ft.*	
1	0.98	31.6	0.82	27.2	[illegible]	[illegible]
2	.95	30.8	.81	27	[illegible]	[illegible]
3	.92	29.9	.84	27.8	[illegible]	[illegible]
4	1.0	32.1	.89	29.1	[illegible]	[illegible]
5	1.08	34.3	.9	29.4	[illegible]	[illegible]
6	1.09	34.5	.91	29.7	[illegible]	[illegible]
7	1.12	35.3	.93	30.2	[illegible]	[illegible]
8	(a)	0	.98	31.6	[illegible]	[illegible]
9	(a)	0	.9	29.4	[illegible]	[illegible]
10	(a)	0	.88	28.9	[illegible]	[illegible]
11	.79	26.4	1.01	32.4	[illegible]	[illegible]
12	1.1	34.8	1.13	35.6	[illegible]	[illegible]
13	1.26	39.1	1.23	38.3	[illegible]	[illegible]
14	1.29	39.9	1.02	32.6	[illegible]	[illegible]
15	1.28	39.7	.94	30.5	[illegible]	[illegible]
16	1.39	42.6	.92	29.9	[illegible]	[illegible]
17	1.35	41.6	.91	29.7	[illegible]	[illegible]
18	1.35	41.6	.87	28.6	[illegible]	[illegible]
19	1.28	39.7	.86	28.3	[illegible]	[illegible]
20	1.19	37.2	1.1	34.8	[illegible]	[illegible]
21	1.16	36.4	1.29	39.9	[illegible]	[illegible]
22	1.11	35.1	1.28	39.7	[illegible]	[illegible]
23	1.19	37.2	1.32	40.7	[illegible]	[illegible]
24	1.09	34.5	1.4	42.9	[illegible]	[illegible]
25	1.26	39.1	1.44	44	[illegible]	[illegible]
26	1.17	36.7	1.55	47	[illegible]	[illegible]
27	1.07	34	1.34	41.3	[illegible]	[illegible]
28	.98	31.6	1.46	44.5	[illegible]	[illegible]
29	.95	30.8	1.51	45.9	[illegible]	[illegible]
30	.91	29.7	1.56	47.3	[illegible]	[illegible]
31	.88	28.9	1.5	45.6		
Mean		[b] 31.8		35.2		

[a] Ditch broken by heavy rains.

[b] For 28 days, 35.2 second-feet.

JETT CREEK DITCH.

Jett Creek ditch was constructed during 1906 to divert water from Jett and Copper creeks over the Nugget divide. The water was turned in from Copper Creek on July 20 and from Jett Creek on August 18, and was turned out on September 25. The ditch carries the total flow of these creeks above the intake up to a maximum of about 10 second-feet.

Discharge measurements on Jett Creek ditch at outlet in 1906.

Date.	Discharge.	Date.	Discharge.
	Sec.-ft.		*Sec.-ft.*
July 21	2.4	September 2	9.2
August 11	.8	September 7	7.2
August 29	4.6	September 10	5.3
August 31	7.3	September 14	3.9

GRAND CENTRAL DITCH.

The completed portion of the Grand Central ditch diverted water from Nugget Creek at an elevation of 785 feet between June 27 and September 29. For measurements of the flow in the ditch see p. 33.

DAVID CREEK DITCH.

David Creek flows into Nome River a short distance below the intake of Miocene ditch. It has a well-sustained flow, which is diverted at an elevation of 590 feet by a ditch leading to and emptying into Nome River just above the Miocene intake. This ditch carries all the flow of David Creek up to 14 second-feet. Its width is 4 feet on the bottom, 6 feet on the top, and when full it has a depth of 1½ feet and a mean velocity of about 1¾ feet per second. The water was running in this ditch before gagings were made on Nome River and was turned out only during extreme high water.

Discharge measurements of David Creek ditch in 1906.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec.-ft.*		*Feet.*	*Sec.-ft.*
July 3		3.5	August 29	0.49	7.6
July 29		6.4	Do	.63	10.1
August 3		4.4	Do	.78	13.7
August 23	0.51	7.9	Do	.81	13.7
August 29	.41	5.4	Do	.68	11.4

Mean daily gage height and discharge of David Creek ditch, 1906.

[Drainage area at point of diversion, 4.3 square miles.]

Day.	August.		Day.	August.	
	Gage height.	Discharge.		Gage height.	Discharge.
	Feet.	*Sec.-ft.*		*Feet.*	*Sec.-ft.*
1	.....	.....	18	.31	
2	.....	.....	19	.29	
3	.....	.....	20	.40	
4	0.25	4.4	21	.38	
5	.35	4.4	22	.50	
6	.35	4.4	23	.52	
7	.42	5.8	24	.48	
8	.38	5.0	25	.54	
9	.37	4.8	26	.77	
10	.37	4.8	27	.34	
11	.38	5.0	28	.4	
12	.4	5.4	29	.42	
13	.38	5.0	30	.78	
14	.35	4.4	31	.80	
15	.34	4.3			
16	.33	4.1	Mean	.....	
17	0.39	5.2			

SEEPAGE MEASUREMENTS ON MIOCENE DITCH.

Measurements were made at different times at several points al the main ditch and also on the Jett Creek branch to determine the l by seepage from the different sections of the ditch. The discha of the branches and principal feeders was found by measuring flow in the ditch above and below them. The results obtained for section between measurements were therefore the resultant of the from creeks too small to measure and the loss by seepage and leak The measurements of July 3 to 4 and on July 27 were made at pe of extreme low water, and show a much larger loss than those of tember 11 to 12, when there was much more water entering. On latter date the ditch was gaining along much of its course. T measurements are of value to ditch builders in showing the l which may be expected in ditches in frozen countries.

Seepage measurements of Miocene ditch, 1906.

MAIN DITCH FROM NOME RIVER TO GLACIER CREEK.

Date.	Point of measurement.	Discharge.	Gain.	
		Sec.-ft.	*Sec.-ft.*	
July 3	Nome River intake	21	.....	
Do	Above Hobson	15.8	.....	
July 4	do	20.5	.....	
Do	Below Hobson	31.0	10.5	
Do	Above flume	28.1	.....	
Do	Below flume	20.8	[illegible]	
Do	Above Ex	27.9	.....	
Do	Above tunnel	28.8	[illegible]	
July 27	Nome River intake	23	.....	
Do	Black Point	25.7	.....	
Do	Above Dorothy	26.2	[illegible]	
Do	Below Dorothy	26.0	.....	
Do	Above Hobson	23.7	.....	
Do	Below Hobson	38.0	14	
Do	Grouse Creek branch	1.7	.....	
	Total above flume	39.7		

Seepage measurements of Miocene ditch, 1906—Continued.

MAIN DITCH FROM NOME RIVER TO GLACIER CREEK—Continued.

Date.	Point of measurement.	Discharge.	Gain.	Loss.
		Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*
July 27	Below flume	36.5		3.2
August 2	do	28.3		
Do	Glacier branch	13.0		
Do	Dexter branch	13.3		
	Total	26.3		2.0
September 11	Nome River at intake	29.8		
Do	Black Point	30.7	.9	
Do	Above Dorothy	30.3		.4
Do	Above Hobson	30		.3
Do	Below Hobson	44.4	14.4	
Do	Grouse Creek branch	2.4		
	Total above flume	46.8		
Do	Below flume	43.9		2.9
September 12	do	[a] 43		
Do	Glacier Fork at Ex	30.3		
Do	Dexter Fork at Ex	15.3		
	Total at Ex	45.6	2.6	
September 13	Glacier Fork at Ex	[a] 29.6		
Do	Above tunnel	29.4		.2
July 29	Intake, David Creek branch	6.9		
Do	Outlet, David Creek branch	6.4		.5

JETT CREEK BRANCH.

September 10	Copper Creek ditch, intake	2.5		
Do	Copper Creek ditch, outlet into Jett Creek ditch	1.8		0.7
Do	Jett Creek ditch, intake	4.2		
	Total	6.0		
Do	Jett Creek ditch, below junction with Copper Creek ditch	5.7		.3
Do	Outlet over Nugget divide	5.3		.4

[a] Estimated.

CAMPION DITCH AT BLACK POINT.

This ditch diverts water from Buffalo Creek at an elevation of 610 feet. Its lower end terminates in Dorothy Creek, into which it discharges. The ditch has a width of 6 feet on bottom and 9 feet on top, is 2 feet deep, and has a mean velocity of 2 feet per second when running full. The water was turned in at 1 p. m. on July 6. The ditch broke near its outlet at 7 a. m. on July 8. It was repaired and water turned in again on the 19th. All water was turned out from 9.30 p. m. August 12 to 2.30 p. m. August 13.

Measurements were taken on the ditch in order to determine the natural flow of Nome River below the junction of Buffalo and Deep Canyon creeks.

Discharge measurements of Campion ditch at Black Point in 1906.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*		*Feet.*	*Sec.-feet.*
July 7	0.80	11.9	August 11	1.36	27.5
July 20	.60	8.9	August 18	.76	12.0
July 21	.70	10.2	August 23	1.10	19.6
August 2	.67	9.7	August 31	1.00	16.8

Mean daily gage height and discharge of Campion ditch, 1906.

[Drainage area at point of diversion, 8.2 square miles.]

Day.	July.		August.		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1			.69	10.1	0.98	16.5
2			.68	10	.9	14.5
3			.65	9.5	1.02	17.5
4			.62	9	1.04	18
5			.56	8.2	1.0	17
6			.61	8.9	1.02	17.5
7	0.88	14.1	.69	10.1	.96	16
8			.7	10.3	.96	16
9			.73	10.9	1.0	17
10			.77	11.7	1.08	19
11			1.13	20.4	1.07	18.8
12			1.05	18.2	1.02	17.5
13			1.09	19.2	1.06	18.5
14			1.02	17.5	1.02	17.5
15			.92	15	.98	16.5
16			.8	12.3	.93	15.2
17			.8	12.3	.92	15
18			.78	11.9	.9	14.5
19			.75	11.3	1.1	19.5
20			.8	12.3	.98	16.5
21			.76	11.5	.5	7.5
22			1.01	17.2	.6	8.7
23			1.16	21.3	.75	11.3
24			.99	16.8	.72	10.7
25	.92	15	.93	15.2	.91	14.8
26	.78	11.9	1.15	21	.96	16
27	.75	11.3	1.16	21.3	1.02	17.5
28	.82	12.7	1.14	20.7	.98	16.5
29	.78	11.9	1.09	19.2	.95	15.8
30	.76	11.5	1.0	17	.94	15.5
31	.72	10.7	.99	16.8		
Mean		12.4		14.4		15.8

SEWARD DITCH.

Seward ditch was built in 1905–6 to take water from Nome River just below Dorothy Creek, at an elevation of 407 feet, and convey it to Saturday Creek for use along the ancient beach line. Its total length is 38 miles. The water is conducted across Hobson and Clara creeks by 42-inch continuous stave-pipe siphons having lengths of 1,050 and 800 feet, respectively.

Measurements to determine the flow and also the seepage of this ditch were made as follows:

Seepage measurements of Seward ditch in 1906.

Date.	Point of measurement.	Discharge.	Gain.	Loss.
		Sec.-feet.	*Sec.-feet.*	*Sec.-feet.*
July 29	Intake	19.7		
Do	Above Clara Creek	20.6	0.9	
Do	Hobson branch	4.0		
		24.6		
Do	Above Trout Creek	22.0		2.6

Other measurements were made at the intake as follows:

Discharge measurements of Seward ditch at intake in 1906.

Date.	Discharge.
	Sec.-feet.
August 18	25
August 30	26
September 13	[a] 32

[a] Estimated.

GRAND CENTRAL RIVER DRAINAGE BASIN.

GENERAL DESCRIPTION.

On account of its elevation and well-sustained flow, Grand Central River offers one of the most valuable unused water supplies of Seward Peninsula. The drainage area of this stream, which is about 12 miles long and 2 miles wide, is almost surrounded by ridges of the Sawtooth Range (Kigluaik Mountains), having elevations of from 1,500 to 4,000 feet (see Pl. VI, *A* and *B*).

The river is formed near the foot of Mount Osborn, at an elevation of about 700 feet, by the junction of North and West forks, and flows in a southerly direction into Salmon Lake.

From the forks to Salmon Lake the river has a fall of about 300 feet, and at high stages spreads over a wide gravelly bed, on either side of which there is a little bottom land, from which the mountains rise abruptly.

The principal tributaries of Grand Central River below the forks are Gold Run and Rainbow creeks from the east, and Thompson, Thumit, Nugget, Jett, and Morning Call creeks from the west. These tributary streams, with the exception of Nugget Creek, drain short, steep-sided gulches. They have considerable fall and are fed from melting snow.

In order to use the water from the drainage at Nome it has to be diverted over the Nugget divide, which has an elevation of 785 feet. One such diversion has been made from Jett Creek and Copper Creek, from which water is taken by the Jett Creek ditch into the Miocene ditch.

The Miocene Ditch Company is building a ditch which will tap West Fork above the mouth of the Crater Lake outlet, and North Fork at an elevation of about 850 feet. This ditch will follow down the west side of the valley, crossing and tapping Thompson and Thumit creeks, and will pass over the Nugget divide, where it will be taken up by the main Miocene ditch and carried to Glacier and Anvil creeks.

The Wild Goose Mining and Trading Company has started from Crater Lake a 42-inch continuous wood-pipe line, which will extend along the south side of the valley over the Nugget divide and down Nome valley to Anvil Mountain. The company plans to dam and use Crater Lake as a storage reservoir, into which the waters from North and West forks will be diverted by lateral pipes. Other laterals will carry the water of Gold Run and Thompson Creek into the main pipe line. Measurements made in this drainage are shown on the following pages.

GRAND CENTRAL RIVER (NORTH FORK).

North Fork of Grand Central River rises in a cirque at the base of Mount Osborn, which is surrounded by almost perpendicular mountains rising from 1,000 to 3,000 feet above the bed of the stream. This cirque contains the remnant of a small glacier, the melting of which maintains a very steady flow. The flow is added to by a large spring at an elevation of about 860 feet.

Discharge measurements on this stream were made at elevations of about 750 feet and 1,030 feet, which points give the flow at the ditch and pipe intakes, respectively. The bed is very rough and it is difficult to obtain satisfactory measuring sections. Gage heights were read at the time of the measurements by measuring down from reference points on rocks.

A. UPPER GRAND CENTRAL RIVER DRAINAGE.

B. MOUNT OSBORN.

Mean daily gage height and discharge of Grand Central River (North Fork), 1906.

[Elevation, 750 feet; drainage area, 5.4 square miles.]

Day.	July.		August.		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1		23		30		44
2		(23)		30	0.92	[b] 44
3		(23)		30		38
4		(25)		32		38
5				32		40
6				29		37
7			0.81	[b] 32		33
8				33		31
9				31	.76	[b] 27
10				33		28
11	1.10	[a] 67		32		27
12				27		(26)
13				27		26
14				28		27
15				28		26
16			.76	[a] 27		25
17			.74	[b] 25		25
18				27		27
19				25		
20		40		27		
21		(45)		(32)		
22	.85	[a] 38		(36)	1.5	[bc] 120
23		42		(60)		
24		61	.85	[b] 37		
25	.95	[a] 47		40		
26	.9	[b] 42		(40)		
27		45		(67)		
28		50		67		
29		38		71		
30		42		54		
31		28		48		
Mean		[d] 39.9		36.7		[e] 31.6
Run-off per square mile		7.39		6.80		5.85
Run-off depth in inches		4.67		7.84		3.92

[a] Measurements.
[b] Estimates based on gage readings.
[c] Not included in mean.
[d] 17 days.
[e] 18 days.

NOTE.—These estimates are made by subtracting the sum of the discharges at the West Fork and Crater Lake station from the flow below the forks. For the days for which this method does not give consistent results the estimates are based on the West Fork flow and are in parenthesis. From July 5 to 19 the flow did not fall below 40 second-feet. The flow on June 26 was 43 second-feet.

Mean daily discharge in second-feet of Grand Central River (North Fork), 1906.

[Elevation, 1,030 feet; drainage area, 2.3 square miles.]

Day.	July.	August.	September.	Day.	July.	August.	September
1	21	22	31	20	31	20	
2	21	22	[a] 31	21	35	24	
3	21	22	27	22	30	27	
4	22	24	27	23	33	45	
5		24	28	24	48	[a] 28	
6		21	26	25	37	30	
7		[a] 23	23	26	[a] 33	30	
8		25	22	27	34	50	
9		23	[a] 19	28	38	50	
10		25	20	29	28	53	
11		24	19	30	32	40	
12		20	17	31	21	36	
13		20	18				
14		21	19	Mean	[b] 30.3	27.4	[c] 22.2
15		21	18	Run-off per square mile	13.2	11.9	9.65
16		20	18				
17		[a] 19	17	Run-off, depth in inches	7.86	13.7	6.46
18		20	19				
19		19					

[a] Measurements. Other discharges are obtained by taking about the same percentage of the flow at elevation 750 feet as was found on the dates of measurements. This varied from 70 to 90 per cent. Gagings on June 20 gave 30 second-feet, and on June 26, 43 second-feet. The flow from July 5 to 19 probably exceeded 35 second-feet.
[b] 16 days.
[c] 18 days.

GRAND CENTRAL RIVER, WEST FORK.

West Fork of Grand Central River has its source in Mount Osborn, and flows between Mount Osborn and the high ridges which separate the Grand Central drainage from the Shuk drainage. It is fed from snow storage for a greater part of the season, and by Crater Lake, which lies at an elevation of 973 feet and has an area of about 106 acres. West Fork did not have as well-sustained flow as North Fork, as much of the snow disappeared during the rain of July 4–12, and thereby reduced the yield from the higher levels for the rest of the summer.

There is considerable glacial drift in the lower part of the area, containing several depressions, one having an area of nearly 5 acres. These fill with water during a rain and gradually drain off through the gravel.

Two gaging stations were established on the fork at elevations of 1,010 feet and 860 feet. The latter is just above the outlet to Crater Lake, and shows the flow at the proposed ditch intake. The conditions for measuring in this section were especially good, and a well-defined rating was obtained. At low water the width of the fork is 17 feet, depth 2 feet, and mean velocity 1.2 feet per second.

The other station was established to obtain the flow at the proposed pipe intake by comparison with the flow at the lower station. The flow was about 70 per cent of that at the lower station during the earlier part of the season. As the snow above the pipe intake melted away and the flow of the springs between the intakes increased, this percentage became about 35 for low water and 50 for higher stages. The cold weather in September checked the flow at high levels and reduced the percentage to 32.

Discharge measurements of Grand Central River (West Fork) in 1906.

[Elevation, 860 feet.]

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*		*Feet.*	*Sec.-feet.*
June 19	.....	40.4	July 22	1.20	35.1
June 20	.....	38	July 24	1.41	58
July 1	.....	28.6	July 25	1.34	50
July 10	1.65	115	August 6	1.12	30.9
July 11	1.53	86	August 16	1.01	23

Mean daily gage height and discharge of Grand Central River (West Fork), 1906.

Elevation, 860 feet; drainage area, 54 square miles.]

Day.	July.		August.		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1	.....	29	1.12	30	1.27	44
2	1.1	28	.....	30	1.24	40
3	1.0	22	.....	30	1.2	36
4	1.1	28	.....	34	1.12	30
5	1.8	162	.....	34	1.08	27
6	.....	.....	1.12	30	1.05	25
7	.....	.....	1.15	32	1.05	25
8	.....	.....	1.11	29	1.02	23
9	.....	.....	.....	26	1.01	23
10	1.65	116	1.02	23	1.0	22
11	1.53	86	1.05	25	1.0	22
12	1.75	144	1.1	28	1.0	22
13	1.6	103	1.08	27	.98	21
14	1.55	90	1.05	25	.95	20
15	1.45	70	.....	24	.92	19
16	1.4	61	1.01	23	.92	19
17	1.45	70	1.0	22	.92	19
18	1.4	61	1.0	22	1.0	22
19	1.3	47	1.0	22	.....	.....
20	1.3	47	.98	21	.....	.....
21	1.35	54	1.12	30	.....	.....
22	1.2	36	1.2	36	1.6	[a] 103
23	1.52	83	1.39	60	.....	.....
24	1.41	63	1.21	37	.....	.....
25	1.33	51	1.16	33	.....	.....
26	1.25	42	1.22	38	.....	.....
27	1.25	42	1.35	54	.....	.....
28	.....	39	1.3	47	.....	.....
29	1.2	36	1.3	47	.....	.....
30	1.15	32	1.27	44	.....	.....
31	1.14	31	.....	44	.....	.....
Mean	.....	[b] 59.8	.....	32.5	.....	[c] 25.5
Run-off per square mile	.....	11.07	.....	6.02	.....	4.72
Run-off, depth in inches	.....	11.12	.....	6.94	.....	3.16

[a] Not included in mean. [b] 27 days. [c] 18 days.

Mean daily discharge, in second-feet, of Grand Central River (West Fork), 1906.

[Elevation, 1,010 feet; drainage area, 2.8 square miles.]

Day.	July.	August.	September.	Day.	July	August.	September.
1	[a] 19	12	22	20	20	7	.....
2	18	12	19	21	23	12	.....
3	15	12	16	22	[a] 15	16	.....
4	18	14	12	23	44	30	.....
5	.....	14	9	24	32	[a] 18.5	.....
6	.....	[a] 12	9	25	[a] 25	15	.....
7	.....	12	8	26	19	19	.....
8	.....	10	8	27	19	27	.....
9	.....	9	[a] 7 3	28	16	24	.....
10	.....	8	7	29	14	24	.....
11	[a] 45	9	7	30	13	22	.....
12	72	11	7	31	12	22	.....
13	52	10	7				
14	45	9	6	Mean	[b] 27.0	13.9	[c] 9.4
15	32	8	6	Run-off per square mile	9.64	4.96	3.36
16	27	8	6				
17	32	[a] 7.6	6	Run-off, depth in inches	8.96	5.72	2.25
18	27	8	7				
19	20	8	.....				

[a] Measurements. Other discharges are obtained by taking about the same percentage of the flow at elevation 860 feet as was found on the dates of measurements. Gagings on June 19 gave 28 second-feet, and on June 26, 26 second-feet.

[b] 25 days.

[c] 18 days.

CRATER LAKE OUTLET.

Crater Lake discharges into West Fork of Grand Central River just below the lower point of measurement on that stream. The lake, which lies in a depression of glacial origin, has an elevation of 973 feet and an area of 106 acres. Its basin adjoins those of Sinuk River and Thompson Creek.

A gaging station was located on the outlet about midway between the lake and West Fork. The stream bed is composed of large angular rocks and has a fall of nearly 300 feet to the mile. It is hard to make measurements on account of the swiftness of the current, and the one at high water is only approximate. Gage heights were taken by employees of the Wild Goose Mining and Trading Company.

Discharge measurements of Crater Lake outlet in 1906.

[Elevation, 925 feet.]

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*		*Feet.*	*Sec.-feet.*
June 19		14.2	July 24	1.10	21.5
June 26		23.7	August 6	.90	7.1
July 1		13.6	August 8	.98	13.0
July 10	1.55	59	August 16	.80	5.6
July 22	.96	12.0	September 9	.73	4.3

Mean daily gage height and discharge of Crater Lake outlet, 1906.

[Drainage area, 1.8 square miles.]

Day.	July.		August.		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1		14	0.85	7	0.98	13
2	1.0	14		7	.94	10
3	1.0	14		8	.9	9
4	1.15	25		8	.82	6
5	1.65	69		9	.78	5
6			.9	9	.78	5
7			.95	11	.78	5
8			.96	12	.75	4.5
9				10	.73	4.3
10	1.55	59	.9	9	.71	4.1
11	1.25	33	.9	9	.69	3.9
12	1.45	50	1.0	14	.68	3.8
13	1.3	37	.95	11	.65	3.5
14	1.15	25	.9	9	.65	3.5
15	1.1	21		7	.61	3.1
16	1.15	25	.8	5.5	.61	3.1
17	1.1	21	.8	5.5	.61	3.1
18	1.05	17	.79	5.5	.75	4.5
19	1.0	14	.8	5.5		
20	1.0	14	.78	5		
21	1.05	17	1.01	15		
22	.96	12	1.01	15	1.4	[a]46
23	1.06	18	1.22	31		
24	1.1	21	1.02	15		
25	1.05	17	1.0	14		
26	1.02	15	1.1	21		
27	1.0	14	1.12	23		
28		12	1.1	21		
29	.9	9	1.05	17		
30	.88	8	1.0	14		
31	.88	8		13		
Mean		[b]22.3		11.8		[c]5.2
Run-off per square mile		12.4		6.56		2.89
Run-off, depth in inches		12.4		7.56		1.98

[a] Not included in mean. [b] 27 days. [c] 18 days.

GRAND CENTRAL RIVER BELOW THE FORKS.

This station was established to obtain the total flow from the headwaters of Grand Central River and also to ascertain the amount that can be diverted over the Nugget divide, as there is but little water coming into the stream between the measuring section and the proposed pipe and ditch intakes. At ordinary stages the river at the measuring point is 50 feet wide, 2 feet deep, and has a mean velocity of 1.2 second-feet. Gage readings were taken by employees of the Wild Goose Mining and Trading Company.

Discharge measurements of Grand Central River below the forks in 1906.

[Elevation, 680 feet.]

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec. feet.*		*Feet.*	*Sec. feet.*
July 1	0.95	63	July 26	1.10	101
July 11	1.40	180	August 7	.89	66
July 24	1.29	140	August 17	.79	54.4
July 24	1.22	129			

Mean daily gage height and discharge of Grand Central River below the forks, 1906.

[Drainage area, 14.6 square miles.]

Day.	July.		August.		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1	0.95	63	0.9	67	1.1	100
2	.9	56	.9	67	1.05	91
3	.95	63	.9	67	1.0	82
4	1.05	80	.95	74	.95	74
5	1.87	370	.....	74	.93	72
6	.....	.....	.9	67	.....	67
7	.....	.....	.98	79	.....	63
8	.....	.....	.94	73	.....	59
9	1.75	325	.9	67	.8	55
10	1.7	300	.....	65	.....	54
11	1.45	198	.....	66	.78	53
12	.....	280	.....	68	.75	50
13	1.45	198	.....	65	.75	50
14	1.42	187	.....	62	.75	50
15	.....	168	.....	59	.72	48
16	.....	160	.81	56	.71	47
17	1.4	180	.79	54	.....	47
18	1.1	100	.....	54	.....	54
19	1.05	91	.....	53	.....	.....
20	1.1	100	.78	53	.....	.....
21	1.1	100	.....	65	.....	.....
22	1.0	82	.....	59	1.72	[a] 310
23	1.28	143	.....	210	.....	.....
24	1.29	145	1.08	96	.....	.....
25	1.18	118	1.02	86	.....	.....
26	1.1	100	.....	140	.....	.....
27	.....	100	.....	210	.....	.....
28	1.1	100	1.25	135	.....	.....
29	1.0	82	1.25	135	.....	.....
30	1.0	82	1.15	111	.....	.....
31	.9	67	1.12	104	.....	.....
Mean	.....	[b] 144	.....	85.2	.....	[c] 62.0
Run-off per square mile	.....	9.86	.....	5.84	.....	4.25
Run-off, depth in inches	.....	10.27	.....	6.73	.....	2.84

[a] Not included in mean. [b] 28 days. [c] 18 days.

NOTE.—The interpolated discharge of Aug. 21-23 and 26-27 are 40 to 45 per cent of the flow at the station below Nugget Creek. This is about the proportion that holds for higher water. Other interpolations are made by comparison with the West Fork and Crater Lake outlet stations.

GRAND CENTRAL RIVER BELOW NUGGET CREEK.

This station was established on June 30, but it was not possible to obtain regular gage readings until August 12, after which date the gage was read once each day by A. W. Peterson. At low water the river at this point is about 50 feet wide, 1 to 2 feet deep, and has a mean velocity of about 2 feet per second. It is impossible to obtain measurements above gage height 1.2 feet by wading. The estimates at this station give practically the total flow of Grand Central River into Salmon Lake.

Discharge measurements of Grand Central River below Nugget Creek, 1906.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*		*Feet.*	*Sec.-feet.*
June 24	.....	313	August 28	1.10	324
June 30	0.57	148	September 9	.46	121
July 7	.98	286	September 14	.36	101
August 4	.46	123			

Mean daily gage height and discharge of Grand Central River below Nugget Creek, 1906.

[Drainage area, 39 square miles.]

Day.	July.		August.		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1	0.5	132	.....	.....	0.8	220
2	.45	120	.....	.....	.75	204
3	.....	.....	.....	.....	.65	172
4	.....	.....	.....	.....	.6	157
5	.....	.....	.....	.....	.6	157
6	.....	.....	.....	.....	.55	141
7	.....	.....	.....	.....	.5	132
8	.....	.....	.....	.....	.5	132
9	.....	.....	.....	.....	.45	120
10	1.9	750	.....	.....	.42	114
11	.....	.....	.....	.....	.4	109
12	1.55	545	0.5	132	.4	109
13	.....	.....	.5	132	.38	105
14	.....	.....	.5	132	.35	100
15	.....	.....	.4	109	.35	100
16	.....	.....	.42	114	.3	90
17	.....	.....	.45	120	.3	90
18	.....	.....	.4	109	.4	109
19	.....	.....	.35	100	1.2	375
20	.....	.....	.5	132	2.6	1,230
21	.6	157	.55	144	2.2	950
22	.....	.....	.5	132	1.6	570
23	.....	.....	1.5	520	1.6	570
24	.....	.....	.8	220	1.35	445
25	.....	.....	.7	187	1.15	352
26	.5	132	1.05	310	.....	.....
27	.....	.....	1.5	520	.....	.....
28	.....	.....	1.1	330	.....	.....
29	.....	.....	.95	272	.....	.....
30	.....	.....	.9	255	.....	.....
31	.....	.....	.8	220	.....	.....
Mean	.....	.....	.....	[a] 210	.....	[b] 274
Run-off per square mile	.....	.....	.....	5.38	.....	7.03
Run-off, depth in inches	.....	.....	.....	4.00	.....	6.54

[a] 20 days. [b] 25 days.

GOLD RUN.

Gold Run enters Grand Central River from the east 2 miles below the forks. It drains a deep gulch, has a very steep grade, and terminates in a large gravel fan, where its flow sinks and disappears.

In order to determine the quantity of water from this stream available for diversion across the Nugget divide a station was established at an elevation of about 800 feet.

Mean daily gage height and discharge of Gold Run, 1906.

[Elevation, 800 feet.]

Day.	July.		August.		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1		14		18		30
2		[a] 13		18	0.95	[b] 26
3		13		18		23
4		20		20		20
5				24		17
6				30		16
7			1.03	[b] 34		15
8			.90	[b] 22		14
9			.89	[b] 21		13
10				20	.71	[a] 12
11		52		20		12
12	1.21	[a] 69		24		12
13		55		22		11
14		45		20		11
15		40		18		11
16		38	.81	[b] 17		10
17		42	.8	[b] 16.5		10
18		24		16		12
19		20		16		
20		22		15		
21		23		28		
22	.84	[a] 18.5		34		
23	1.0	[b] 30		50		
24		30		34		
25	1.00	[a] 30	.99	[b] 29		
26	.93	[b] 24		44		
27		24		68		
28		21	1.13	[a] 51		
29		20		40		
30		19		36		
31		18		32		
Mean		[c] 29.0		27.6		[d] 15.3

[a] Measurements.
[b] Estimates based on gage heights. Other estimates were made by plotting a hydrograph passing through the known points and following the rise and fall of the other streams in the vicinity. Gagings made on June 20 gave 22 second-feet and on June 25, 24 second-feet.
[c] 25 days.
[d] 18 days.

THOMPSON CREEK.

Thompson Creek enters Grand Central River from the west about 2 miles below the forks. It drains a small glacial cirque almost wholly surrounded by very steep walls ranging from 1,000 to 2,000 feet high. Measurements were made at a point with an elevation of 720 feet, which gives the amount of water available for diversion over the Nugget divide.

Daily gage height and discharge of Thompson Creek, 1906.

[Elevation, 720 feet. drainage area, 2.5 square miles.]

Day.	July.		August.		Septe
	Gage. Height.	Discharge.	Gage Height.	Discharge.	Gage Height.
	Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*
1		11		9	
2		[a] 11		9	
3		11		10	
4		16		10	
5				11	
6				15	
7			1.39	[b] 22.5	
8			1.22	[b] 14	
9			1.19	[a] 12.5	1.0
10				11	1.0
11		36		11	
12		[a] 52		17	
13		40		14	
14		30		12	
15		24		11	
16		28	1.11	[b] 9.6	
17		23	1.12	[b] 10	
18		19		10	
19		16		10	
20		16		9	
21		18		20	
22	1.2	[b] 13		20	
23		21		40	
24	1.42	[a] 25	1.4	[b] 23	
25	1.41	[a] 23		21	
26	1.29	[b] 17.5		28	
27		16		30	
28		14		28	
29		11	1.44	[b] 25.4	
30		11		22	
31		10		30	
Mean		[c] 20.5		16.6	
Run-off per square mile		8.20		[d] 6.64	
Run-off, depth in inches		7.62		7.[illegible]	

[a] Measurements.

[b] Estimates based on gage heights. Other estimates were made by plotting a hydrograph through the known points and following the rise and fall of Crater Lake outlet, which [illegible] that of Thompson Creek and is of a similar character. A measurement on June 25 gave [illegible]

[c] 25 days.

[d] 18 days.

NUGGET AND COPPER CREEKS.

Nugget Creek rises in the divide between Nome River and Central River and empties its waters and those of its tri Copper Creek, into Grand Central River about 2 miles above Lake.

The headwaters of both Nugget and Copper creeks are qu cipitous and are said to be fed by springs in limestone. M ments were made on Nugget Creek at an elevation of 785 fee point of the diversion of its waters over the Nugget divide Grand Central ditch.

The flow of Copper Creek is also tapped by a branch of t Creek ditch at an elevation of about 800 feet.

Discharge measurements of Nugget and Copper creeks in 1906.

NUGGET CREEK.

[Elevation, 785 feet.]

Date.	Elevation of point of measurement.	Discharge.	Date.	Elevation of point of measurement.	Discharge.
	Feet.	*Sec.-feet.*		*Feet.*	*Sec.-feet.*
June 18		1.8	August 11		3.0
June 19		1.6	August 29		8.6
June 21		4.4	September 2		6.8
June 28		.96	September 7		6.1
July 12		6.8	September 14		4.4

COPPER CREEK.

June 18	700	3.8	July 21	800	2.4
June 19	800	8.7	August 11	800	.8
June 21	700	11.6	August 31	800	6.6
July 12	700	11.3	September 10	800	2.4

JETT CREEK.

Jett Creek enters Grand Central River from the south. It has a short drainage and is made up of a series of falls and rapids. Water is diverted over the Nugget divide into Nome River by the Jett Creek ditch (see p. 19 for measurements on Jett Creek ditch).

Measurements were made to show the amount of water available at the diversion.

Discharge measurements of Jett Creek in 1906.

[Elevation, 800 feet.]

Date.	Discharge.	Date.	Discharge.
	Sec.-feet.		*Sec.-feet.*
June 19	14.9	July 21	5.8
July 2	4.4	August 31	8.3
July 12	14.3	September 10	4.2

MORNING CALL CREEK.

Morning Call Creek enters Grand Central River from the south near Salmon Lake. The hills to the south are lower and more exposed than in the case of Copper and Jett creeks, and the snow melts earlier in the spring. At low water all the flow disappears in the previous limestone above the point where a ditch intended to cross the Nugget divide would have its intake. The water appears again near the contact with the schist, at an elevation of about 750 feet.

Discharge measurements of Morning Call Creek in 1906.

Date.	Elevation of point of measurement.	Discharge.	Date.	Elevation of point of measurement.	Discharge.
	Feet.	*Sec.-feet.*		*Feet.*	*Sec.-feet.*
June 20	700	36	July 2	700	10.0
June 20	900	24.6	July 12	700	20.8
June 24	500	27.3	August 9	900	0.0

SALMON LAKE.

Salmon Lake lies at the foot of the Kigluaik Mountains at an elevation of about 442 feet. It has a water surface area of 1,800 acres and a drainage area of 81 square miles. Its principal supply comes from Grand Central River, which enters it at its western end. A number of small streams also enter the lake from both the north and the south, but with the exception of Fox Creek and Jasper Creek these are of minor importance. The outlet of the lake is through Kruzgamepa River.

This lake offers an excellent opportunity for a storage reservoir for power purposes and mining along Kruzgamepa River. The use of its water in the vicinity of Nome is practically prohibited owing to its low elevation and the long tunnel which would be necessary to bring the water through the Nugget divide into the Nome River basin. By raising the water of the lake to an elvation of 500 feet the shortest tunnel line would be between 5 and 6 miles long; and if any allowance be made for drawing on the storage, water could not be brought through to the Nome Valley at an elevation greater than about 450 feet. The mouth of the tunnel would be near Dorothy Creek, and the loss in grade between there and Nome would bring the water so low that it could not be used to any extent for hydraulicking. Even if the water could be brought to the vicinity of Nome under a sufficient head for hydraulicking, the great cost and difficulty of building so long a tunnel would make the feasibility of the plan very doubtful.

Measurement of flow in and out of Salmon Lake in 1906.

Date.	Stream.	Discharge.
		Sec.-feet.
June 22	Rainbow Creek	3.4
Do	Fox Creek	99
Do	8 small streams from north	[a] 6
June 24	Jasper Creek	11.6
Do	Morning Call Creek	27
Do	Jett Creek	[a] 10
Do	6 small streams from south	[a] 4
Do	Grand Central River below Nugget Creek	313
	Total	474
June 23	Kruzgamepa River, at outlet of Salmon Lake	425

[a] Estimated.

NOTE.—The stage of Salmon Lake remained practically constant June 22-24, inclusive.

A measurement on Fox Creek on August 16 gave a discharge of 17.3 second-feet.

KRUZGAMEPA RIVER DRAINAGE BASIN BELOW SALMON LAKE.

GENERAL DESCRIPTION.

Kruzgamepa, or Pilgrim, River, the outlet of Salmon Lake, has a larger discharge than any other stream in this section. For about 12 miles it follows a valley ranging from 6 to 12 miles in width, and

then enters the lowlands north of the Kigluaik Range, and finally discharges into Imuruk Basin. The principal tributaries are Crater, Grouse, and Homestake creeks from the north and Iron Creek from the south.

As it leaves Salmon Lake the river flows through a narrow outlet having a width of 150 feet at the bottom and 500 feet at the top, offering an excellent dam site and location for a hydro-electric power plant. Plans for the construction of such a plant have been perfected by the Salmon Lake Power Company, which plans to develop 3,000 horsepower, to be used on dredges at Nome and Council and on Solomon River.

Salmon Lake, at its present level, 442 feet, covers 1,800 acres; if raised to a level of 475 feet it would cover 3,600 acres; and at 500 feet, 4,600 acres. The reservoirs thus formed may be used for the storage of the water of the floods caused by the melting snow in the spring and the occasional heavy rains in the summer. The water thus retained will give a large minimum flow not only in summer but also during the winter months, when the natural run-off becomes small.

Kruzgamepa River seldom freezes over before the first of January, and it is probable that with proper installation power could be developed throughout the year.

KRUZGAMEPA RIVER AT OUTLET OF SALMON LAKE.

A gaging station was established at Leland's camp, about 100 yards below the lake. During the spring flood a temporary gage had been set by Mr. John P. Samuelson and read twice a day. Float measurements were also made, which gave a discharge considerably smaller than the open-water flow, showing a backwater effect caused by snow banks in the channel below. This effect became less as the water fell and the snow banks melted.

A new gage was set June 23, with its datum 3 feet below that of the temporary gage. The old gage heights were reduced to the datum of the new gage by adding 3 feet. A tagged wire stretched across the river gave distances from the initial point. Measurements were made by wading at low water and up to a gage height of 1.5 feet. At higher stages it was impossible to reach the middle of the stream, because of the depth and velocity of the water, and float measurements were resorted to.

The gage was read twice daily by Mr. John P. Samuelson. The natural storage in the lake regulated the flow, making the rise and fall very gradual, and the gage readings give the mean height of the lake very closely.

A change in channel occurred during the high water of July 8 to 9, the soundings showing a scour in the middle of the gaging section of

about 0.2 foot, and the increase in velocity indicating an even greater scour below. No low-water measurements could be obtained after the high water of September 21 to 23, but it is believed that no change occurred.

Discharge measurements of Kruzgamepa River at outlet of Salmon Lake in 1906.

	Area of section.	Mean velocity.	Gage height.	Discharge.
	Square feet.	*Ft. per sec.*	*Feet.*	*Second-feet.*
June 23	183	2.32	1.22	425
June 29	170	2.08	1.00	353
June 30	157	2.01	.93	315
July 9	431	5.43	3.18	2,340
Do	412	5.09	3.02	2,094
July 10	372	4.73	2.68	1,760
August 4	117	1.81	.38	212
August 15	116	1.80	.37	209
August 25	148	2.11	.70	312
August 26	159	2.33	.80	371
August 28	184	2.49	1.02	458
September 1	164	2.27	.85	373
September 7	127	1.95	.52	248
September 17	108	1.62	.27	175
September 21	336	4.61	2.38	1,546
September 23	299	3.76	2.06	1,124
September 24	269	3.44	1.80	925

Mean daily gage height and discharge of Kruzgamepa River at Salmon Lake.

[Drainage area, 81 square miles.]

	May.		June.		July.		August.		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
1			3.05	1,780	0.82	272	0.48	239	.86	387
2			3.75	2,270	.72	241	.42	221	.81	364
3			3.9	2,350	.7	235	.38	209	.74	336
4			4.2	2,520	.7	235	.36	203	.69	316
5			3.75	2,270	.8	265	.38	209	.65	300
6			3.2	1,920	1.1	380	.38	209	.6	280
7			2.45	1,220	1.1	380	.4	215	.53	256
8					1.92	1,030	.4	215	.49	242
9					3.05	2,130	.4	215	.46	233
10					2.6	1,640	.36	203	.41	218
11					2.2	1,275	.35	200	.39	212
12					1.95	1,065	.35	200	.37	206
13					1.85	985	.36	203	.34	197
14					1.55	768	.34	197	.31	188
15					1.45	702	.36	202	.3	185
16					1.25	582	.35	200	.28	180
17					1.12	511	.32	197	.26	175
18					1.08	490	.3	185	.27	178
19					.98	441	.26	175	.52	252
20					.9	405	.32	191	1.34	634
21					.82	369	.39	212	2.35	1,410
22					.85	382	.42	221	2.4	1,455
23			1.2	420	.82	369	.66	304	2.11	1,198
24			1.25	442	.85	382	.71	324	1.78	930
25			1.2	420	.82	369	.7	320	1.58	787
26			1.12	388	.8	360	.76	344	1.38	658
27			1.1	380	.72	328	.9	405	1.22	566
28	5.45	3,270	1.05	360	.7	320	1.02	460	1.08	490
29	5.0	3,000	1.02	348	.62	288	1.05	475	.98	441
30	4.05	2,430	.92	308	.55	262	.99	446	.88	396
31	3.6	2,180			.5	245	.94	423		
Mean		2,720	[a] 2,050	[b] 383		571		259		456
Run-off per square mile		33.6	25.3	4.73		7.05		3.20		5.63
Run-off, depth in inches		5.00	6.59	1.41		8.13		3.69		6.28
Run-off in acre-feet		21,600	28,500	6,040		35,100		15,900		27,100

[a] June 1 to 7.

[b] June 23 to 30.

CRATER CREEK.

Crater Creek is the first large tributary entering Kruzgamepa River from the north. It rises in mountains that reach an elevation of nearly 4,000 feet. The topography and general character of its basin closely resemble those of the Grand Central River. (See page 23.) It drains many small lakes, but none of any considerable size. This stream has good possibilities for water-power development. Measurements were made at an elevation of about 550 feet.

Discharge measurements of Crater Creek in 1906.

[Elevation 550 feet.]

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
	Feet.	*Sec.-feet.*		*Feet.*	*Sec.-feet.*
August 5		67	September 1	0.71	110
August 15	0.45	57	September 8	.45	55
August 27	1.30	290	September 16	.35	39

IRON CREEK.

Iron Creek rises in an area of limestone and schist hills of no great elevation lying between Salmon Lake and the headwaters of Casadepaga and Eldorado rivers. It is formed by the junction of Eldorado and Telegram creeks. Its principal tributaries are Discovery and Canyon creeks, both from the southwest. The portion of the stream above Discovery Creek is sometimes called Dome Creek. Iron Creek empties into Kruzgamepa River about 12 miles below Salmon Lake.

Several mines are being worked successfully on this stream and its tributaries. During 1906 the Gold Beach Development Company built a ditch 13 miles long, which diverts water from Eldorado, Discovery, and Canyon creeks, for use on Discovery No. 1 and No. 2 claims on Iron Creek.

Measurements of Iron Creek and tributaries in 1906.

Date.	Stream.	Elevation.	Discharge.
		Feet.	*Sec.-feet.*
August 14	Iron Creek	450	[a] 17.1
September 15	do	425	[a] 26.1
August 14	Iron (Dome) Creek	630	6.0
September 15	do	630	5.0
August 13	Eldorado Creek	750	4.5
September 15	do	750	5.6
August 13	Discovery Creek	740	1.25
September 15	do	740	2.3
August 13	Canyon Creek	760	1.3
September 15	do	760	1.1

[a] Below Canyon Creek.

about 0.2 foot, and the increase in velocity indicating an even greater scour below. No low-water measurements could be obtained after the high water of September 21 to 23, but it is believed that no change occurred.

Discharge measurements of Kruzgamepa River at outlet of Salmon Lake in 1906.

	Area of section.	Mean velocity.	Gage height.	Discharge
	Square feet.	*Ft. per sec.*	*Feet.*	*Second-feet.*
June 23	183	2.32	1.22	[illegible]
June 29	170	2.06	1.00	[illegible]
June 30	157	2.01	.93	[illegible]
July 9	431	5.43	3.18	2,340
Do	412	5.09	3.02	2,094
July 10	372	4.73	2.66	1,760
August 4	117	1.81	.38	[illegible]
August 15	116	1.80	.37	[illegible]
August 25	148	2.11	.70	[illegible]
August 26	159	2.33	.80	[illegible]
August 28	184	2.49	1.02	[illegible]
September 1	164	2.27	.85	[illegible]
September 7	127	1.95	.52	[illegible]
September 17	108	1.62	.27	[illegible]
September 21	336	4.61	2.38	[illegible]
September 23	299	3.76	2.06	[illegible]
September 24	269	3.44	1.80	[illegible]

Mean daily gage height and discharge of Kruzgamepa River at Salmon Lake.

[Drainage area, 81 square miles.]

	May.		June.		July.		August.		September.	
	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
	Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
1			3.05	1,780	0.82	272	0.48	239	.86	[illegible]
2			3.75	2,270	.72	241	.42	221	.81	[illegible]
3			3.9	2,350	.7	235	.38	209	.74	[illegible]
4			4.2	2,520	.7	235	.36	203	.69	[illegible]
5			3.75	2,270	.8	265	.38	209	.65	[illegible]
6			3.2	1,920	1.1	380	.38	209	.6	[illegible]
7			2.45	1,220	1.1	380	.4	215	.53	[illegible]
8					1.92	1,030	.4	215	.49	[illegible]
9					3.05	2,130	.4	215	.46	[illegible]
10					2.6	1,640	.36	203	.41	[illegible]
11					2.2	1,275	.35	200	.39	[illegible]
12					1.95	1,065	.35	200	.37	[illegible]
13					1.85	985	.36	203	.34	[illegible]
14					1.55	768	.34	197	.31	[illegible]
15					1.45	702	.36	202	.3	[illegible]
16					1.25	582	.35	200	.28	[illegible]
17					1.12	511	.32	197	.26	[illegible]
18					1.08	490	.3	185	.27	[illegible]
19					.98	441	.26	175	.32	[illegible]
20					.9	405	.32	191	1.34	624
21					.82	369	.39	212	2.35	1,410
22			1.2	420	.85	382	.42	221	2.4	1,455
23			1.25	442	.82	369	.66	304	2.11	1,190
24			1.2	420	.85	382	.71	324	1.78	950
25			1.12	388	.82	369	.7	320	1.58	787
26			1.1	380	.8	360	.76	344	1.38	658
27	5.45	3,270	1.05	360	.72	328	.9	405	1.22	566
28	5.0	3,000	1.02	348	.7	320	1.02	460	1.06	490
29	4.05	2,430	.92	308	.62	288	1.05	475	.98	441
30	3.6	2,180			.55	262	.99	446	.88	396
31					.5	245	.94	423		
Mean		2,730	[a] 2,050	[b] 383		571		259		450
Run-off per square mile		33.6	25.3	4.73		7.05		3.20		5.63
Run-off, depth in inches		3.90	6.39	1.41		8.13		3.69		6.38
Run-off in acre-feet		21,600	28,500	6,040		35,100		15,900		27,100

[a] June 1 to 7.

[b] June 23 to 30.

[illegible]

Crater Creek is the [illegible] Kruzgamepa River from the north. It [illegible] elevation of nearly 4,000 feet. The [illegible] of its basin closely resemble those of the [illegible] River. (See page 23.) It drains many [illegible] lakes [illegible] considerable size. This stream has good [illegible] for water-power development. Measurements were made at an [illegible] feet.

[illegible]

[illegible]

Date.	[illegible]	[illegible]	Date.	[illegible] height	Discharge
	Feet.	[illegible]		Feet.	Sec. feet.
August 5		[illegible]	September 1	[illegible]	[illegible]
August 15	[illegible]	[illegible]	September 8	[illegible]	[illegible]
August 27	[illegible]	[illegible]	September 16	[illegible]	[illegible]

IRON CREEK.

Iron Creek rises in an area of limestone and schist hills of [illegible] elevation lying between Salmon Lake and the headwaters of [illegible] paga and Eldorado rivers. It is formed by the junction of [illegible] and Telegram creeks. Its principal tributaries are [illegible] Canyon creeks, both from the southwest. The portion [illegible] above Discovery Creek is sometimes called Dom[illegible] Creek empties into Kruzgamepa River about 12 [illegible] Lake. [illegible] he

Several mines are being worked successfully [illegible] ited tributaries. During 1906 the Gold Beach [illegible] the built a ditch 13 miles long, which divert[illegible] covery, and Canyon creeks, for use on [illegible] to *Miocene* claims on Iron Creek.

Measurements of Iron Cr[illegible]

Date.	[illegible]	[illegible]	Total fall.	Elevation above sea level. Intake.	Elevation above sea level. Outlet.
		[illegible]	Feet.	Feet.	Feet.
August 14	Iron Creek	[illegible]	27	820	793
September 15	do	15	18	793	775
August 14	Iron (Dome) Creek	4.5	17	770	753
September 15	do	4	7	753	746
August 13	Eldorado Creek	6	26	746	720
September 15	do	4	86	562	476
August 13	Discovery Creek	3-7			
September 15	do				
August 13	Canyon Creek	[illegible]			
September 15	do	[illegible]			

[illegible] of Windy Creek in a siphon [illegible] feet long

Length of ditch, pipe, and tunnel necessary to carry water from Sinuk River to Miocene flume—Continued.

BY TUNNEL AND GOLDBOTTOM CREEK.

Section.	Kind of construction.	Length.	Fall per mile.	Total fall.	Elevation above sea level. Intake.	Elevation above sea level. Outlet.
		Miles.	*Feet.*	*Feet.*	*Feet.*	*Feet.*
Windy Creek to Sinuk River	Pipe	1.8	15	27	820	793
	Ditch	[a] 4.1	4.5	18	793	775
Sinuk River to tunnel	do	4.2	4	17	770	753
Sinuk River through to Silver Creek	Tunnel	1.1	6	7	753	746
Silver Creek to Goldbottom Creek	Ditch	[b] 12.4	4	51	705	654
Goldbottom Creek to flume	do	9.2	4	37	513	476
Total	Ditch	29.9				
	Pipe	1.8				
	Tunnel	1.1				

BY DITCH AND SIPHONS ACROSS STEWART RIVER AND GOLDBOTTOM CREEK.

Windy Creek to Sinuk River	Pipe	1.8	15	27	820	793
	Ditch	[a] 4.1	4.5	18	793	775
Sinuk River to Siphon	do	20.0	4	80	770	690
Near Francisco Creek to below Mountain Creek.	Pipe	1.5	35	52	690	638
Siphon to Goldbottom divide	Ditch	2.0	4	8	638	630
Goldbottom Creek to flume	do	9.2	4	37	513	476
Total	Ditch	35.3				
	Pipe	3.3				

[a] 2.1 miles of ditch may be avoided by carrying the water of Windy Creek in a siphon 3,500 feet long across Sinuk River.
[b] 6.1 miles of ditch may be replaced by 1.2 miles of siphon across Stewart River.

UPPER SINUK RIVER.

The gagings on the upper Sinuk were made at an elevation of 770 feet, and show the probable water supply which could be diverted from this stream for any of the plans just described.

Discharge measurements of upper Sinuk River in 1906.

[Elevation, 770 feet; drainage area, 6.2 square miles.]

Date.	Discharge.	Date.	Discharge.
	Sec.-feet.		*Sec.-feet.*
June 27	33	August 3	20
July 6	37	August 10	23.5
July 20	36		

WINDY CREEK.

Windy Creek, the first large tributary of Sinuk River, lies between the main ridge of the Kigluaik Mountains and the headwaters of the Sinuk. It adjoins the west fork of Grand Central River, from which it may be reached by crossing a high divide. The topography is very rough, the creek being entirely lost in some places in the large bowlders which form its bed.

Discharge measurements of Windy Creek in 1906.

Date.	Elevation at point of measurement.	Discharge.	Date.	Elevation at point of measurement.	Discharge.
		Sec.-feet.			*Sec.-feet.*
June 21	1,100	49	August 3	650	32
June 27	1,100	17	August 10	650	[b] 35
July 13	[a] 650	114	September 6	650	[b] 32
July 20	650	48			

[a] Drainage area, 12 square miles. [b] Estimated.

NORTH STAR CREEK.

North Star Creek lies between Sinuk River and Windy Creek, and is a tributary to the latter near its mouth. It is a small stream with a steep slope.

Discharge measurements of North Star Creek in 1906.

[Elevation, 900 feet; drainage area, 2.3 square miles.]

Date.	Discharge.	Date.	Discharge.
	Sec.-feet.		*Sec.-feet.*
June 27	9.8	July 20	3.9
July 6	18.1	August 3	3.0
July 13	16.4	August 10	2.9

STEWART RIVER.

Stewart River lies south of upper Sinuk River, to which it is tributary. It drains an area of limestone and schist hills. The flow is small and the stream of minor importance.

Discharge measurements of Stewart River in 1906.

[Elevation, 400 feet.]

Date.	Discharge.	Date.	Discharge.
	Sec.-feet.		*Sec.-feet.*
July 15	72	July 30	[a] 26
July 17	49	August 19	11.4

[a] Estimated.

SLATE CREEK.

Slate Creek is the second tributary to Stewart River from the north. The following gives approximate measurements of the flow that can be diverted into Nome River over Divide Creek:

Discharge measurements of Slate Creek in 1906.

[Elevation, 700 feet; drainage area, 2.1 square miles.]

Date.	Discharge.	Date.	Discharge.
	Sec.-feet.		*Sec.-feet.*
July 15	6.7	July 30	2.8
July 17	4.4	August 19	2.2

OTHER SINUK RIVER DRAINAGE.

For measurements on Josie, Irene, and Jessie creeks, which are small tributaries of Stewart River, see below.

CRIPPLE RIVER DRAINAGE BASIN.

GENERAL DESCRIPTION.

Cripple River enters Bering Sea about 12 miles west of Nome, after draining an area of about 88 square miles.

As yet but little mining has been done in this section, except in the vicinity of Oregon and Hungry creeks. Some small ditches have been constructed at the headwaters of Cripple River, the principal one being the Cedric, which diverts water from the Stewart River drainage.

CEDRIC DITCH.

The Cedric ditch was built in 1905 to divert water from Josie and Jessie creeks (tributary to the Stewart River) over the divide to the Cripple River basin for use on Oregon, Hungry, Trilby, and Nugget creeks. After passing the divide it picks up water from upper Oregon (2 forks), Slate, and Aurora creeks, which are its principal feeders, and from Daisy Swift Creek, Snowshoe Gulch, and three other small gulches. It has a total length of about 19 miles and a width of from 4 to 8 feet. The elevation of the head is about 870 feet and of the outlet 790 feet. The capacity of the lower half is about 25 second-feet. Water is carried across Oregon Creek near the outlet by a siphon 2,970 feet long, of 30-inch riveted steel pipe. There are about 6 miles of distributing ditches at the lower end.

The following measurements were made to determine the amount of water available for the ditch:

Water available for Cedric ditch in 1906.

Stream.	July 15-17.	July 30-31.	August 19.
	Sec.-feet.	*Sec.-feet.*	*Sec.-feet.*
Josie Creek	3.0	1.5	1.[illegible]
Irene Creek	1.0	[a] .8	[a] .[illegible]
Jessie Creek	[b] 3.2	2.6	.[illegible]
Upper Oregon Creek	[b] 6.8	2.6	.....
Slate Creek	4.0	2.0	.....
Aurora Creek	4.8	2.1	.....
Daisy Swift Creek	.5	.....	.....
Total available for ditch	18.3	11.6	.....

[a] Estimated.
[b] Measured below ditch level; only about half this amount is available for the ditch.

Seepage measurements on Cedric ditch.

Date.	Point of measurement.	Discharge.	Loss.	Distance.	Loss per mile.
		Sec.-feet.	*Sec.-feet.*	*Miles.*	*Sec.-feet.*
July 30	Below upper Oregon Creek	2.6			
Do	Above Slate Creek	1.9	0.7	2.3	0.3
Do	Below Slate Creek	3.9			
July 31	Above Aurora Creek	3.1	.8	1.8	.4
Do	Below Aurora Creek	5.2			
Do	Above Daisy Swift Creek	4.7	.5	2.0	.25
Do	Below Daisy Swift Creek	4.5	.2	.6	.3
Do	At penstock	2.5	2.0	3.7	.5
	Total		4.2	10.4	.4

PENNY RIVER DRAINAGE BASIN.

Penny River enters Bering Sea a little east of the mouth ot Cripple River, and has a drainage area of 36 square miles. Its waters are being used by the United Mining Company on the tundra near the old beach, and are diverted by means of two ditches.

The following measurements were made in the Penny River drainage:

Date.	Point of measurement.	Elevation.	Discharge.
		Feet.	*Sec.-feet.*
August 1	Below intake of high-line ditch	420	7.8
Do	Sutton ditch at intake	120	30.0
Do	Penny River below Sutton ditch intake	120	6.2

SNAKE RIVER DRAINAGE BASIN.

Snake River empties into Bering Sea at Nome. It has a drainage area of 110 square miles, which contains some of the richest mining ground in the Seward Peninsula, notably the claims on Glacier, Anvil, and Little creeks. Owing to the slight fall its use for mining purposes is limited to ground sluicing. All the available water from both the main stream and its tributaries is being used, and water is diverted into this area by the Miocene ditch, the Seward ditch, and the Nome River ditch of the Pioneer Mining Company.

FLAMBEAU AND ELDORADO RIVER DRAINAGE BASINS.

These streams rise near Salmon Lake and flow in a southerly direction to Bering Sea near Cape Nome. Because of their minor importance, but one measurement was made upon them. The flow of Eldorado River was measured August 14 below the mouth of Venetia Creek and found to be 44 second-feet.

AVAILABLE WATER SUPPLY DURING 1906.

In order to determine the amount of water that could have been used during 1906 for hydraulicking the placers near Nome, the mean flow of the streams in each drainage basin has been tabulated by weekly periods in the table on page 45. In using this table the following points should be noted:

The "high-level flow of Nome River" represents the total amount of water in that river above Miocene ditch, including the flow of Campion ditch, David Creek, and Hobson Creek. The flow of the springs on the latter creek has been taken as 14 second-feet, except for the first week in July, when it did not exceed 10 second-feet.

"Low-level flow, Nome River," includes all additional water down to the Pioneer ditch. This has been estimated on basis of drainage area as equal to 90 per cent of the naural flow at Miocene intake, plus about 3 second-feet at Hobson Creek.

"Grand Central River" includes the station below the forks and those on Thompson Creek and Gold Run, and gives the amount that can be brought over the Nugget divide.

The mean flow of "Nugget, Copper, and Jett creeks" gives the amount that can be brought over the Nugget divide, and was estimated from the few measurements obtained.

The flow of "Sinuk River and its tributaries, Windy and North Star creeks," has been estimated for an elevation of 800 feet, which is as low as the water can be taken over the divide into Nome River (see p. 39).

The amount of this flow was obtained by taking 70 per cent of the flow of Grand Central River below the forks, this percentage being determined as follows:

Comparison of flow of Grand Central River below forks with that of Sinuk River and its tributaries at elevation 800 feet.

Date.	Sinuk River.	Windy Creek.	North Star Creek.	Total.	Grand Central below forks.	Sinuk, Windy, and North Star in per cent of Grand Central.
	Sec.-feet.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	
June 26, 27	33	22	10	65	105	[illegible]
July 6	37	(35)	18	90	.....	.....
July 13	(75)	86	16	177	198	[illegible]
July 20	36	36	4	76	100	[illegible]
August 3	20	24	3	47	67	[illegible]
August 10	23.5	26	3	52.5	65	[illegible]
September 6	(20)	24	(3)	47	67	[illegible]

The drainage areas of Grand Central River, Sinuk River, and Windy and North Star creeks lie adjacent to each other on the north and the south side, respectively, of Kigluaik Mountains. On the days when measurements of flow were made of the streams on

both sides of the mountain it was found, as shown in the preceding table, that the flow on the south side was from 62 to 89 per cent of the flow on the north side. It is, therefore, conservative to say that the average combined flow of Sinuk River and Windy and North Star creeks will be 70 per cent of the flow of Grand Central River below the forks.

The following table should not be taken as indicating the water that can be used. This will, of course, be limited by the capacity of ditches that can be built economically. In the ecnomical construction of a ditch the size will depend largely upon the duration of the low-water flow. This will probably limit the size in most cases to twice the minimum, except for short ditches.

Mean weekly water supply, in second-feet, available for use back of Nome, 1906.

Dates.	Available for use at elevation 250 to 275 feet.	Available for use at elevation 400 to 450 feet.				
	Nome River low level.	Nome River high level.	Upper Grand Central, Thompson, and Gold Run.	Nugget, Copper, and Jett creeks.	Sinuk River, Windy and North Star creeks.	Total.
July 1-7	31	45	153	7	88	324
July 8-14	110	144	343	26	173	796
July 15-21	36	58	179	15	90	378
July 22-28	29	49	156	12	79	325
July 29-August 4	22	42	101	8	50	223
August 5-11	26	45	108	8	49	236
August 12-18	34	53	91	8	42	228
August 19-25	58	84	138	10	62	352
August 26-September 1	94	128	202	22	94	540
September 2-9	48	73	101	14	51	287
September 9-18	33	53	68	9	36	199
September 18-30	86	118	250	20	125	599
Mean	51	74	158	13	78	375
Maximum	110	144	343	26	173	796
Minimum	22	42	68	7	36	199

WATER SUPPLY AVAILABLE FOR OTHER YEARS AND LOCALITIES.

But little definite information in regard to climatic and other conditions at Nome prior to 1900 is known. The climatic conditions of that year are described by the old residents as very similar to those for 1906, both being dry and warm seasons. The years 1901, 1902, 1904, and 1905 are described as being wet and cold; 1903 was dry in the eastern portion of the peninsula. There were, therefore, two years of drought out of a total of seven, and it is probable that similar low-water periods will occur every few years.

Notwithstanding the fact that the flow for 1906 was as a whole below the normal, there were weeks when it probably reached an

absolute summer maximum; for instance, the second week i
The rain storm of July 8 was one of the severest which ha
known in that section, and owing to the frozen condition
ground practically all this rain ran off within a few days and
maximum high-water flow to nearly all the streams (see fig. 1).
weeks beginning August 16 and September 18 there was also
erable rain, and these weeks were probably typical of high
The week beginning July 29 probably showed as small a flow
be expected before the cold weather lessens the yield of high l

The above-described conditions are due to the fact that t
cipal source of water supply of this country is the rainfall
appears almost immediately in the streams. Therefore a ver
storm, even in a dry season, will give the same conditions of f
similar storm during a wet season. The above table of week
therefore, can be used as a general criterion for hydraulic deve
in this section.

In order to predict what the flow would be in other areas si
Seward Peninsula the following tables have been prepared,
the absolute daily minimum and the mean monthly flow, in
feet per square mile, for the various streams.

These streams have been grouped into two classes: (1) tho
in foothills, having southern exposures and but few gulches i
snow can be stored; (2) streams rising in mountainous are
northern exposures and many gulches in which snow is st
held during the whole summer.

The minimum and mean flow can be obtained, approxim
multiplying the drainage area of a stream by the flow per squ
given in the tables for a stream of similar character.

Minimum daily flow of streams in Seward Peninsula during

STREAMS RISING IN FOOTHILLS

Stream.	Elevation.	Date.	Minimum flow.	
	Feet.		*Second-feet.*	*Sec*
Iron Creek below mouth of Canyon Creek	450	Aug. 14	17.1	
Eldorado River below mouth of Venetia Creek	400	do	44	
Jett Creek	800	Sept. 10	[a] 4.2	
Copper Creek	800	Aug. 11	8	
Nugget Creek	785	June 28	[a]	
David Creek	500	Aug. 19	4.8	4
Dorothy Creek	500	Aug. 18	2.0	
Hobson Creek	500	July 4	10.5	
Slate Creek (tributary of Stewart)	700	Aug. 19	2.2	
Stewart River	400	do	11.4	
Penny River	120	Aug. 1	[a] 36	

[a] Lowest measurements obtained. The flow was less on certain dates.
[b] The lowest flow later in the season was 3.0 second-feet, or 1.4 second-feet per square mile.
[c] The flow of Hobson Creek is from large limestone springs whose catchment area [illegible] with the surface watershed.

Minimum daily flow of streams in Seward Peninsula during 1906—Continued.

STREAMS RISING IN KIGLUAIK MOUNTAINS.

Stream.	Elevation.	Date.	Minimum flow.	Drainage area.	Minimum run-off per sq. mi.
	Feet.		*Sec.-feet.*	*Sq. miles.*	*Sec.-feet.*
Grand Central River (North Fork)	750	July 1	23	5.4	4.3
Grand Central River (West Fork)	850	Sept. 15 to Sept. 17	19	5.4	3.5
Grand Central River below the forks	690	Sept. 16 to Sept. 17	47	14.6	3.1
Grand Central River below Nugget Creek	455	....do...	90	39	2.3
Between station below the forks and station at Nugget Creek	.....	....do...	43	24.4	1.76
Crater Lake outlet	925	Sept. 15 to Sept. 17	3.1	1.8	1.7
Thompson Creek	720	Sept. 16 to Sept. 17	5	2.5	2.0
Windy Creek	650	Aug. 3	32	12	2.7
North Star Creek	900	Aug. 10	2.9	2.3	1.26
Sinuk River	770	Aug. 3	20	6.2	3.2
Buffalo Creek	800	....do...	9.1	4.4	2.1
Nome River	575	Aug. 5	20	15	1.3
Fox Creek	550	Aug. 16	17.3	11	1.6
Crater Creek	550	Sept. 16 to Sept. 17	39	.....	.....
Kruzgamepa River	442	Aug. 19 to Sept. 17	175	81	2.16

Mean run-off, in second-feet per square mile, at gaging stations.

Station.	Drainage area.	July 1-31.	July 1-4 and 11-31	Aug. 1-31.	Sept. 1-30.	Sept. 1-18
	Sq. mi.					
Grand Central River (North Fork), elevation 750 feet	5.4	.....	[a] 7.53	6.80	.....	5.85
Grand Central River (North Fork), elevation 1,030 feet	2.3	.....	.....	11.9	.....	9.65
Grand Central River (West Fork), elevation 860 feet	5.4	.....	10.3	6.02	.....	4.72
Grand Central River (West Fork), elevation 1,010 feet	2.8	.....	9.64	4.96	.....	3.36
Crater Lake outlet	1.8	.....	10.8	6.56	.....	2.89
Thompson Creek	2.5	.....	8.20	6.64	.....	3.04
Grand Central River below the forks	14.6	.....	8.36	5.84	.....	4.25
Grand Central River below Nugget Creek	39	.....	.....	[a] 4.42	.....	3.36
Kruzgamepa River at outlet Salmon Lake	81	7.05	.....	3.20	5.63	3.05
Between Grand Central River below the forks and Kruzgamepa River stations	66	.....	.....	2.62	.....	2.79
Nome River at Miocene intake	15	3.43	2.71	3.36	4.29	.....

[a] Approximate.

DITCH AND PIPE LINES.

In order to bring the water to the gold-producing ground between Capes Nome and Rodney at sufficient elevation to be used for hydraulicking and sluicing, nearly 300 miles of ditch and pipe line have been constructed and several extensive additional systems are now under construction or consideration. The first ditch in this section was built in 1901, by W. L. Leland and J. M. Davidson, from upper

ing on the material.

The work of constructing a ditch is usually classes: (1) Team work; (2) pick and shovel work.

Teams may be used in handling dry soil that c sized rock. This is the fastest method, and th lower banks by the horses and scrapers makes when the dirt is thrown in loose.

Pick and shovel are used in loose rock, in w ground from which the top is removed as it tha

Rock must be blasted, unless it is fissured li be loosened with the crowbar, or decomposed s the pick. In building through solid rock, a about 1 foot below grade and wide enough to the lower bank, which is built of rocks. The b are lined with sod about 1 foot thick, and are p

In rock slide the method is similar. A good of construction was seen on the Grand Central b system. The ditch was built through a pil unmixed with any soil or gravel. A trench wa and 2 feet wider than the finished ditch. The were lined with a slope wall, laid 1 to 1, to a l The outer slope of the lower bank was also rock flatter. The ditch will be lined with sod and w manent.

or no sediment between them. In this case the ditch must be lined with sod and all holes must be filled by tamping sod into them as far as possible. This being done, it will be found that the water traveling through the ditch will deposit sediment over the sod and that after a little while it will ' ecome tight.

Canvas is also used as a lining to secure water-tightness. Willows with the tops left out, so that they may grow, are utilized in embankments with success.

In construction over "glacier," which is the term used for frozen muck mixed with ground ice, the ditch is either built wholly on top of the sod covering or an excavation is made and lined with sod. Ditches over this material are expensive to maintain, owing to the thawing of ice by running water.

One of the most interesting pieces of construction over glacier is the flume on the Miocene ditch. This flume is 1,100 feet long, and has a width of 8 feet and a depth of 28 inches. It was constructed in 1901, and is now in practically perfect alignment, both horizontal and vertical, and no repairs have been necessary on it. In putting in the foundation, trenches were dug 3 or 4 feet deep in the frozen ground, which was practically all ice. The excavated material was covered to protect it from thawing. A sill was laid in the bottom of the trench and the uprights fastened to this sill. The excavated material was then replaced in the trenches and froze again into the original condition. Sod was carefully placed over the trench. The uprights were then sawed off to grade and the flume constructed on them.

Inverted siphons are built across deep ravines where their use will save expense and reduce loss by seepage. Most of these are of riveted steel pipe. Joints are made by lapping the ends from 4 to 6 inches. Siphons must be weighted down and protected by rock to prevent injury by frost and snow slides. During 1906 two siphons were built on the Seward ditch, across Clara and Hobson creeks, using continuous wood-stave pipes with steel bands.

On account of the rapid surface run-off during hard rains, it is necessary to have frequent waste gates. The most common waste gates consist either of a flume as deep as the bottom of the ditch, in which the height of the water is regulated by flashboards, or of a long weir, laid on the ground surface, which will spill the water when it reaches a certain level.

Intakes of ditch consist of a dam or barrier across the stream, containing one or more waste gates, and head-gates for regulating the flow into the ditch. In order to divert the entire flow of a stream, a bed-rock dam must be built to stop the ground flow through the gravelly beds. These are made by cutting a trench across the stream

bed, extending down to an impervious stratum, and filling it with sod, which is carefully laid and tamped. The dam should be protected from erosion with large flat rocks or riprap.

Frozen ground, inadequate facilities for transportation, and high cost of help[a] and supplies make ditching very expensive. To the first cost of a ditch should be added the cost of maintenance for the first three years, during which time extensive repairs are necessary. These in many cases equal the first cost of construction. At the end of three years ditches are, as a rule, in fairly permanent condition, and the cost of maintenance is greatly reduced. Such information as could be obtained shows that the cost of a ditch carrying from 1,000 to 2,000 inches, including the first three years' maintenance, is from $5,000 to $8,000 per mile. Owing to dangers from washouts and landslides, it is necessary to have the ditch constantly patrolled.

Owing to the frozen condition of the ground, it is not practicable to use ditches much before the 1st of July, as the surface does not become fully thawed until that time, and during the thawing period the ground becomes very soft and there is great danger of damage by washouts.

The following table gives a list of the principal ditches in this section. The data given are in some cases only approximate, as it was necessary to obtain them by inquiry.

Ditches between Cape Nome and Cape Rodney, Seward Peninsula.

Name.	Extends		Length.	Completed.	Bottom width.	Fall per mile.	Capacity.	Elevation.	
	From—	To—						Head	Outlet.
Miocene Ditch Co.:			*Miles.*		*Feet.*	*Feet.*	*Sec.-feet.*		
Main ditch...	Nome River...	Hobson Creek.	13	1903	8	4.5	40	572	500
	Hobson Creek.	The Ex.....	14	1902	10	3.37	55	500	445
	The Ex.....	Snow Gulch ...	4	1901	8	6.5	55	445	420
Feeding laterals.	Upper Glacier Creek.	The Ex.....	2	1901	.....	.....	6	.....	445
	Grouse Creek..	Flume.....	4	.....	.....	.....	4	.....	478
	Upper New Eldorado Creek.	Sparkle Creek..	7	1906	.....	.....	6	742	.....
	David Creek...	Nome River above main intake.	1.8	.....	4	.....	14	590	.....
	Jett Creek.....	Nugget Divide.	3.5	1906	3.5	6	10	806	785
	Grand Central River.	.....do.....	8	(b)	8-10	5-6	80	850	785
Distributing laterals.	The Ex.....	Grass Gulch...	4	.....	6	3.3	16	445	432
Tunnel.....	Kanema Gulch, Glacier Creek.	New Year Gulch, Anvil Creek.	c 1,800	1904	d 4x7	.....	.....	.....	.....
Wild Goose Mining and Trading Co.:									
Seward.....	Nome River below Dorothy Creek.	Saturday Creek.	38	1906	10	3.18	32	408	274
Pipe line.....	Crater Lake...	Nugget Divide.	8	(b)	e 42	15	60	963	.....
	Nugget Divide.	Anvil Mountain.	35	(b)	e 48	10	70	.....	.....
	Pumping plant.	.....do.....	7	.....	e 18	.....	6	.....	.....
	No. 3, below Little Creek.	Pumping plant.	3	1902	4	5.3	6	.....	.....

[a] Laborers receive $5 per day and board; blacksmiths, cooks, etc., $6.
[b] Under construction.
[c] Feet.
[d] Cross section.
[e] Diameter in inches.

Ditches between Cape Nome and Cape Rodney, Seward Peninsula—Continued.

Name.	Extends		Length.	Completed.	Bottom width.	Fall per mile.	Capacity.	Elevation.	
	From—	To—						Head	Outlet.
Pioneer Mining Co.:			*Miles.*		*Feet.*	*Feet.*	*Sec.-feet.*		
South bank..	No. 2, above Anvil Creek.	No. 1, below Anvil Creek.	0.75	1902	5	7	4–6	.....	.....
North Bank..	No. 4, above Anvil Creek.	Moonlight Reservoir.	1.25	1903	6	.....	10–12	.....	.....
	Nome River, above Clara Creek.	Little Creek...	38	1906	8	3	40	.....	.....
United Ditch Co.:									
Sutton.....	Penny River...	Beach.....	6	1905	20–15	3.12	100	120	90
Highline.....	....do.....	....do.....	.....	[a] 1904	7	4.22	.....	420	.....
Miscellaneous:									
Cedric.....	Josie Creek....	Hungry Creek.	19	1905	4–8	4	25	870	790
Campion.....	Buffalo.....	Dorothy Creek.	4	1903	6	7.5	28	610	580
Northwestern Ditch Co.	Osborn Creek..	Hastings Beachline.	18	.....	.....	.....	20	.....	.....
Northland Mining Co.	Goldbottom Creek.	Balto Creek...	12	([a])	.....	.....	20	390	.....
Hot Air.....	Divining.....	Glacier Creek opposite Snow Gulch.	6	1902	.....	.....	10	.....	.....
Price and Tremper.	Glacier Creek..	Opposite Snow Gulch.	2.5	.....	.....	.....	5	175	.....
Golden Dawn	Twin Mountain Creek.	Alpha Creek...	10	([a])	.....	.....	20	500	.....
Corson Mining Co.	Last Chance Creek.	Pioneer Gulch..	4	1903	.....	.....	18	400	.....
Plein.....	No. 7, Otter Creek.	Mouth.....	1	1904	.....	.....	3	.....	.....
Flambeau Hastings.	Head of Flambeau River.	Hastings Creek	29	1906	.....	.....	20	.....	.....
Capt. Peterson.	No. 3, below Anvil.	Little Creek...	2.5	.....	.....	.....	16	.....	.....
Cripple River Hydraulic Mining Co.	West bank Cripple River.	.....	10	.....	.....	.....	.....	.....	.....
Jourden-Cummings.	Buffalo Creek..	Boer Creek....	4	1906	4	6	20	1,000	.....

[a] Under construction.

WATER-POWER POSSIBILITIES.

Owing to the great value of water in this section of the country for use in the auriferous gravels, but little attention has been given to power development. There are, however, a large number of excellent power sites on various portions of the peninsula whose development is feasible, both from an engineering and a financial standpoint.

The scarcity of fuel makes steam power very expensive, and it is probable that much of the future mining, especially along the tundra back of Nome and along the larger streams, will be carried on by dredging or by some form of elevating in which power will play an important part. With this in view the attention of mining men should be directed to the consideration of power possibilities. Among those which were observed are the Salmon Lake development, which has been started; the development at Nugget Divide, by bringing over the water from Grand Central River; the developments at Divide Creek and Gold Bottom Creek, possible in connection with the diversion of the Sinuk

water; the Glacier Lake power, and many other powers in the streams of the Kigluaik Mountains, notably on the glacier-fed torrents on their northerly slope. (See p. 38.)

NOTES FOR INVESTORS.

Present information shows that the total water supply available for use in the vicinity of Nome, and probably in other parts of Alaska, is limited. Caution, therefore, should be used in extensive hydraulic developments.

There is a great tendency in that country to push forward construction and the installation of expensive machinery before making a preliminary investigation to determine the feasibility of the project from an engineering and from a financial standpoint. A large portion of the ditch and other hydraulic work already constructed in this section has been a failure from the first, both on account of insufficient water supply and the lack of mineral ground on which to use the supply if it were available, and also in many cases from inefficient construction.

Furthermore, there is a great tendency for individuals and companies to undertake the construction and installation of expensive plants without employing the services of an engineer. This has resulted in total or partial failure, due both to the excessive cost and the inefficiency of the plant, where a successful development should have been made.

The cost of useless machinery, ditches, etc., which are to be seen almost everywhere in this section of the country, amounts to hundreds of thousands of dollars. This condition and the tendency for immature development should be noted by all who are looking toward this region for investment, and investments should be preceded by a thorough investigation by competent engineers.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 196.]

The serial publications of the United States Geological Survey consist of (1) Annual Reports, (2) Monographs, (3) Professional Papers, (4) Bulletins, (5) Mineral Resources, (6) Water-Supply and Irrigation Papers, (7) Topographic Atlas of United States—folios and separate sheets thereof, (8) Geologic Atlas of the United States—folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists can be had on application.

Most of the above publications can be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they can be obtained, free of charge (except classes 2, 7, and 8), on application.

2. A certain number are delivered to Senators and Representatives in Congress for distribution.

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